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ERRATA.

Page 588, line 10 from bottom, cancel p at the end of the formula, which should be

$$v\frac{Ct}{p}-\tfrac{1}{4}AJK\left(\frac{278{\cdot}7}{t}\right)^2.$$

— 755, 7 lines from bottom, *for* Plate A. *read* Plate XXVII.

— 864, 8 lines from bottom of text, *for* fig. 2 *read* fig. 3.

— — 6 lines from bottom of text, *for* fig. 3 *read* fig. 2.

— 869, 13 lines from bottom of text, *for* more *read* less.

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Adjudication of the Medals of the Royal Society for the year 1862 by the President and Council.

The Copley Medal to Thomas Graham, Esq., F.R.S., for three Memoirs on the Diffusion of Liquids, published in the Philosophical Transactions for 1850 and 1851; for a Memoir on Osmotic Force in the Philosophical Transactions for 1854; and particularly for a Paper on Liquid Diffusion applied to Analysis, including a distinction of Compounds into Colloids and Crystalloids, published in the Philosophical Transactions for 1861.

The Rumford Medal to Professor Kirchhoff, of Heidelberg, for his Researches on the fixed Lines of the Solar Spectrum, and on the inversion of the bright lines in the Spectra of artificial light.

A Royal Medal to the Rev. Dr. T. R. Robinson, F.R.S., of Armagh, for the Armagh Catalogue of 5345 Stars, deduced from observations made at the Armagh Observatory, from the year 1826 up to 1854; for his Papers on the Construction of Astronomical Instruments, in the Memoirs of the Astronomical Society, and his Paper on Electro-Magnets, in the Transactions of the Royal Irish Academy.

A Royal Medal to Professor Alexander W. Williamson, F.R.S., for his Researches on the Compound Ethers, and his subsequent communications in Organic Chemistry.

The Bakerian Lecture was delivered by Warren De La Rue, Esq., F.R.S.: it was entitled "On the Total Solar Eclipse of July 18th, 1860, observed at Rivabellosa, near Miranda de Ebro, in Spain."

The Croonian Lecture was delivered by Professor A. Kölliker, For. Memb. R.S.: it was entitled "On the Termination of Nerves in Muscles, as observed in the Frog; and on the Disposition of the Nerves in the Frog's Heart."

XXV. *On the Thermal Effects of Fluids in Motion.*—Part IV.

By J. P. Joule, *LL.D., F.R.S. &c., and Professor* W. Thomson, *A.M., LL.D., F.R.S. &c.*

Received June 19,—Read June 19, 1862.

In the Second Part of these researches we have given the results of our experiments on the difference between the temperatures of an elastic fluid on the high- and low-pressure sides of a porous plug through which it was transmitted. The gases employed were atmospheric air and carbonic acid. With the former, 0°·0176 of cooling effect was observed for each pound per square inch of difference of pressure, the temperature on the high-pressure side being 17°·125. With the latter gas, 0°·0833 of cooling effect was produced per lb. of difference of pressure, the temperature on the high-pressure side being 12°·844.

It was also shown that in each of the above gases the difference of the temperatures on the opposite sides of the porous plug is sensibly proportional to the difference of the pressures.

An attempt was also made to ascertain the cooling effect when elastic fluids of high temperature were employed; and it was satisfactorily shown that in this case a considerable diminution of the effect took place. Thus, in air at 91°·58, the effect was only 0°·014; and in carbonic acid at 91°·52, it was 0°·0474.

In the experiments at high temperatures there appeared to be some grounds for suspecting that the apparent cooling effect was too high; for the quantity of transmitted air was very considerable, and its temperature possibly had not arrived accurately at that of the bath by the time it reached the porous plug.

The obvious way to get rid of all uncertainty on this head was to increase the length of the coil of pipes. Hence in the following experiments the total length of 2-inch copper pipe immersed in the bath was 60 feet instead of 35, as in the former series. The volume of air transmitted in a given time was also considerably less. There could therefore be no doubt that the temperature of the air on its arrival at the plug was sensibly the same as that of the bath.

The nozle employed in the former series of experiments was of box-wood,—the space occupied by cotton-wool, or other porous material, being 2·72 inches long and an inch and a half in diameter. The box-wood was protected from the water of the bath by being enveloped by a tin can filled with cotton-wool. This was unquestionably in most respects the best arrangement for obtaining accurate results; but it was found necessary to make each experiment last one hour or more before we could confidently depend on the thermal effect. The oscillations of temperature which took place during the first

part of the time were traced to various causes, one of the principal being the length of time which, on account of the large capacity for heat and the small conductivity of the box-wood nozle, elapsed before the first large thermal effects consequent on the getting up of the pressure were dissipated. No doubt the results we arrived at were very accurate with the elastic fluids employed, viz. atmospheric air and carbonic acid; but we possessed an unlimited supply of the former and a supply of the latter equal to 120 cubic feet, which was sufficient to last for more than half an hour without being exhausted. In extending the inquiry to gases not so readily procured in large quantities, it was therefore desirable to use a porous plug of smaller dimensions enclosed in a nozle of less capacity for heat, so as to arrive rapidly at the normal effect.

Various alterations of the apparatus were made in order to meet the new requirements of our experiments. A small high-pressure engine of about one horse-power was placed in gear with a double-acting compressing air-pump, which had a cylinder $4\frac{1}{2}$ inches in diameter, with a length of stroke of 9 inches. The engine was able to work the piston of the pump sixty complete strokes in the minute. The quantity of air which it ought to have discharged at low pressure was therefore upwards of 16,000 cubic inches per minute. But much loss, of course, occurred from leakage past the metallic piston, and in consequence of the necessary clearance at the top and bottom of the cylinder when the pressure increased by a few atmospheres; so that in practice we never pumped more than 8000 cubic inches per minute.

The nozle we employed will be understood by inspecting Plate XXVI. fig. 1, where *a a* is the upright end of the coil of copper pipes. On a shoulder within the pipe a perforated metallic disk (*b*) rests. Over this is a short piece of india-rubber tube (*c c*) enclosing a silk plug (*d*), which is kept in a compressed state by the upper perforated metallic plate (*e*). This upper plate is pressed down with any required force by the operation of the screw *f* on the metallic tube *g g*. A tube of cork (*h h*) is placed within the metallic tube, in order to protect the bulb of the thermometer from the effects of a too rapid conduction of heat from the bath. Cotton-wool is loosely packed round the bulb, so as to distribute the flowing air as evenly as possible. The glass tube (*i i*) is attached to the nozle by means of a piece of strong india-rubber tubing, and through it the indications of the thermometer are read. The top of the glass tube is attached to the metallic tube *l l*, for the purpose of conveying the gas to the meter.

The thermometer (*m*) for registering the temperature of the bath is placed with its bulb near the nozle. The level of the water is shown by *n n*; and *o o* represents the wooden cover of the bath.

When a high temperature was employed, it was maintained by introducing steam into the bath by means of a pipe led from the boiler. The water of the bath was in every case constantly and thoroughly stirred, especially when high temperatures were used.

The general disposition of the apparatus will be understood from fig. 2, in which A represents the boiler, B the steam-engine geared to the condensing air-pump C. From this pump the compressed air passes through a train of pipes 60 feet long and 2 inches

in diameter, and then enters the coil of pipes in the bath D. Thence, after issuing from the porous plug, it passes through the gasometer E, and ultimately arrives again at the pump C. This complete circulation is of great importance, inasmuch as it permits the gas which has been collected in the meter to be used for a much longer period than would otherwise have been possible. A glass vessel full of chloride of calcium is placed in the circuit at F, and chloride of calcium is also placed in the pipe at *f*. A small tube leading from the coil is carried to the shorter leg of the glass siphon gauge G, of which the longer leg is 17 feet, and the shorter 12 feet long.

The thermometers employed were all carefully calibrated, and had about ten divisions to the degree Centigrade. We took the precaution of verifying the air- and bath-thermometers from time to time, especially when high temperatures were used, in which latter case a comparison between the thermometers at high temperature was made immediately after each experiment.

Atmospheric Air.

In the experiments described in the present paper, the air was not deprived of its carbonic acid. It was simply dried by transmitting it in the first place, before it entered the pump, through a cylinder 18 inches long and 12 inches in diameter filled with chloride of calcium, and afterwards, in its compressed state, through a pipe 12 feet long and 2 inches in diameter filled with the same substance. The experiments were principally carried on in the winter season; so that the chloride kept dry for a long time. From its condition after some weeks' use, it was evident that the water was removed, almost as much as chloride of calcium can remove it, after the air had traversed three inches of the chloride contained by the first vessel.

TABLE I.

No. of experiment.	Cubical inches of air transmitted per minute.	Pressure over that of the atmosphere, in inches of mercury.	Temperature of the bath.	Thermal effect.	Correction on account of conduction of heat.	Corrected thermal effect.	Thermal effect reduced to the pressure of 100 inches of mercury.	Time occupied by experiment, in minutes.	Number of observations comprised in each mean.	Extreme range of the temperature of the bath.	Extreme range of the temperature of the air.	Extreme range of the pressure.
1	3000	83·96	4·499	−0·711	−0·044	−0·755	−0·900	14	5	0·020	0·015	2·25
2	3600	136·19	6·112	−1·11	−0·058	−1·168	−0·858	24	7	0·017	0·055	1·7
3	3600	156·59	6·082	−1·307	−0·094	−1·401	−0·895	15	5	0·009	0·065	3·0
4	1750	139·58	7·471	−1·137	−0·122	−1·259	−0·902	24	15	0·006	0·19	5·3
5	2250	153·9	7·640	−1·231	−0·103	−1·334	−0·867	12·5	10	0·008	0·028	3·8
6	2200	149·3	8·546	−1·232	−0·102	−1·334	−0·850	18	20	0·017	0·105	3·0
7	2080	165·73	8·2	−1·329	−0·121	−1·450	−0·875	14	15	0·024	0·128	4·8
8	1500	129·73	8·72	−1·019	−0·127	−1·146	−0·883	8	9	0·006	0·125	2·9
9	5000	138·9*	24·92	−0·953	−0·037	−1·020	−0·791	12	8	0·015	0·09	7·0
10	4000	122·6	27·81	−0·874	−0·036	−0·910	−0·741	26	15	0·029	0·064	0
11	5000	123·5	42·64	−0·947	−0·036	−0·983	−0·796	8	4	0·127	0·122	7·0
12	4800	137	43·54	−0·943	−0·037	−0·980	−0·715	6	3	0·02	0·02	0
13	5000	137·5	47·92	−0·937	−0·037	−0·974	−0·764	6	4	0·058	0·09	2·0
14	3700	147	49·96	−0·969	−0·049	−1·018	−0·692	35	30	0·14	0·26	0
15	5400	146	52·375	−0·860	−0·028	−0·888	−0·608	28	20	0·05	0·08	0
16	5700	146	64·9	−0·870	−0·029	−0·899	−0·616	24	20	0·18	0·23	0
17	2700	112·43	89·901	−0·469	−0·033	−0·502	−0·446	30	10	0·112	0·23	3·6
18	1700	147	90·353	−0·921	−0·091	−0·912	−0·620	4	3	0·029	0·085	0
19	1700	153·16	92·486	−0·756	−0·083	−0·839	−0·547	19	10	0·202	0·273	7·0
20	3150	156·5	92·603	−0·674	−0·040	−0·714	−0·456	12	10	0·078	0·19	3·5
21	3800	146	93·78	−0·700	−0·036	−0·736	−0·504	24	20	0·236	0·255	0
22	4600	158·5	97·528	−0·722	−0·029	−0·751	−0·474	20	16	0·112	0·115	0
1	2	3	4	5	6	7	8	9	10	11	12	13

Oxygen Gas.

This elastic fluid was procured by cautiously heating chlorate of potash mixed with a small quantity of peroxide of manganese. In its way to the meter it passed through a tube containing caustic potash, in order to deprive it of any carbonic acid it might contain. The same drying-apparatus was employed as in the case of atmospheric air.

TABLE II.

No. of experiment.	Cubical inches of elastic fluid transmitted per minute.	Composition of the elastic fluid.	Pressure over that of the atmosphere, in inches of mercury.	Temperature of the bath.	Thermal effect.	Correction on account of conduction of heat.	Corrected thermal effect.	Thermal effect reduced to the pressure of 100 inches of mercury.	Ditto, calculated for pure oxygen.	Time occupied by experiment, in minutes.	Number of observations comprised in each mean.	Extreme range of the temperature of the bath.	Extreme range of the temperature of the elastic fluid.	Extreme range of the pressure.
1	2000	5·095 N 94·905 O	159·28	8°·682	−1°·547	−0°·145	−1°·692	−1°·061	−1°·075	9	10	0°·007	0°·35	7·8
2	2000	54·62 N 45·38 O	161·81	8·75	−1·373	−0·129	−1·502	−0·928	−1·074	11	10	0·017	0·046	0·9
3	1700	3·64 N 96·36 O	151	89·466	−1·069	−0·118	−1·187	−0·786	−0·800	14	10	0·45	0·43	6·2
4	3150	22·37 N 77·63 O	159·77	90·8	−0·840	−0·050	−0·890	−0·557	−0·580	12	10	0·326	0·336	8·0
5	3150	51·03 N 48·97 O	154·1	92·792	−0·734	−0·043	−0·777	−0·504	−0·527	12	10	0·18	0·19	4·0
6	4500	4 N 96 O	152	95·453	−0·795	−0·033	−0·828	−0·544	−0·570	11	8	0·135	0·158	0
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

Nitrogen Gas.

In preparing this gas the meter was first filled with air, and then a long shallow tin vessel was floated under it, containing sticks of phosphorus so disposed as to burn in succession. Some hours were allowed to elapse after the combustion had terminated, in order to allow of the deposition of the phosphoric acid formed.

TABLE III.

No. of experiment.	Cubical inches of elastic fluid transmitted per minute.	Composition of the elastic fluid.	Pressure over that of the atmosphere, in inches of mercury.	Temperature of the bath.	Thermal effect.	Correction on account of conduction of heat.	Corrected thermal effect.	Thermal effect reduced to the pressure of 100 inches of mercury.	Ditto, calculated for pure nitrogen.	Time occupied by experiment, in minutes.	Number of observations comprised in each mean.	Extreme range of the temperature of the bath.	Extreme range of the temperature of the elastic fluid.	Extreme range of the pressure.
1	2050	7·9 O 92·1 N	163·38	7°·204	−1°·448	−0°·133	−1°·581	−0°·967	−1°·034	7	8	0°·008	0°·25	6·2
2	2500	2·2 O 97·8 N	162·65	91·415	−0·857	−0·064	−0·921	−0·567	−0·576	13	10	0·036	0·48	4·5
3	2500	12·5 O 87·5 N	164·61	91·965	−0·869	−0·065	−0·934	−0·567	−0·691	12	9	0·337	0·378	3·0
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

Carbonic Acid.

This gas was formed by adding sulphuric acid to a solution of carbonate of soda. It was dried in the same manner as all the other gases.

TABLE IV.

No. of experiment.	Cubical inches of elastic fluid transmitted per minute.	Composition of the elastic fluid.	Pressure over that of the atmosphere, in inches of mercury.	Temperature of the bath.	Thermal effect.	Correction on account of conduction of heat.	Corrected thermal effect.	Thermal effect reduced to the pressure of 100 inches of mercury.	Ditto, calculated for pure carbonic acid, calling its sp. heat for equal vol. 1·30.	Time occupied by experiment, in minutes.	Number of observations comprised in each mean.	Extreme range of the temperature of the bath.	Extreme range of the temperature of the elastic fluid.	Extreme range of the pressure.
1	2450	68·42 Air 31·58 CO_2	163·7	7·362	−2·699	−0°190	−2°889	−1°765	−3°166	12	10	0°	0°16	3·2
2	2350	89·16 Air 10·84 CO_2	148·82	7·360	−1·621	−0·125	−1·746	−1·173	−2·990	14	10	0·004	0·282	9·2
3	3100	3·52 Air 96·48 CO_2	164·07	7·384	−6·719	−0·299	−7·018	−4·277	−4·367	6·5	6	0·008	0·021	1·4
4	2500	62·5 Air 37·5 CO_2	162·925	7·407	−2·839	−0·191	−3·030	−1·860	−3·032	8	8	0·007	0·11	5·8
5	2300	88·13 Air 11·87 CO_2	158·08	7·433	−1·682	−0·132	−1·814	−1·147	−2·648	10	10	0·005	0·107	5·2
6	2260	97·46 Air 2·54 CO_2	163·52	7·608	−1·407	−0·116	−1·523	−0·931	−2·753	8	8	0·007	0·064	2·0
7	3300	4·0 Air 5·286 H 90·714 CO_2	161·97	7·960	−6·131	−0·262	−6·393	−3·947	−4·215	6	8	0	0·18	4·8
8	3000	4·23 Air 46·47 H 49·3 CO_2	153·72	8·020	−2·189	−0·117	−2·306	−1·500	−2·631	5	5	0	0·19	1·6
9	1500	7·09 Air 67·05 H 25·86 CO_2	97·56	8·296	−0·543	−0·063	−0·606	−0·622	−1·940	15	15	0·012	0·146	5·4
10	2925	2·11 Air 97·89 CO_2	167·25	93·523	−3·418	−0·160	−3·578	−2·139	−2·164	10	10	0·382	0·49	4·0
11	2925	56·78 Air 43·22 CO_2	167·4	91·26	−1·746	−0·099	−1·845	−1·102	−1·674	30	20	0·292	0·49	11·0
12	2925	77·77 Air 22·23 CO_2	146·83	91·642	−1·292	−0·077	−1·369	−0·938	−2·053	9	6	0·045	0·245	3·5
13	5500	0·83 Air 99·17 CO_2	146	54·0	−4·184	−0·104	−4·288	−2·937	−2·951	24	16	0·24	0·46	0
14	5300	67·7 Air 32·3 CO_2	147	49·703	−1·832	−0·059	−1·891	−1·286	−2·225	24	16	0·025	0·17	0
15	5600	87·77 Air 12·23 CO_2	145	49·764	−1·250	−0·032	−1·282	−0·884	−2·025	20	16	0·01	0·11	0
16	5100	1·83 Air 98·17 CO_2	127·5	35·604	−4·186	−0·112	−4·298	−3·371	−3·407	18	15	0·03	0·095	0
17	5000	1·66 Air 98·34 CO_2	151	97·553	−3·11	−0·084	−3·194	−2·115	−2·135	20	16	0·292	0·272	0
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

Hydrogen.

Our method in procuring this elastic fluid was to pour sulphuric acid, prepared from sulphur, into a carboy nearly filled with water and containing fragments of sheet zinc. The gas was passed through a tube filled with rags steeped in a solution of sulphate of copper, and then through a tube filled with sticks of caustic potash. The rags became speedily browned, and we therefore adopted the plan of pouring a small quantity of solution of sulphate of copper from time to time into the carboy itself. This succeeded perfectly; the rags retained their blue colour, and the gas was rendered perfectly inodorous, whilst at the same time its evolution became much more free and regular.

TABLE V.

No. of experiment.	Cubical inches of elastic fluid transmitted per minute.	Composition of the elastic fluid.	Pressure over that of the atmosphere, in inches of mercury.	Temperature of the bath.	Thermal effect.	Correction on account of conduction of heat.	Corrected thermal effect.	Thermal effect reduced to the pressure of 100 inches of mercury.	Ditto, calculated for pure hydrogen.	Time occupied by experiment, in minutes.	Number of observations comprised in each mean.	Extreme range of the temperature of the bath.	Extreme range of the temperature of the elastic fluid.	Extreme range of the pressure.
1	3000	17·635 Air 82·365 H	64·1	δ·24	−δ·144	−δ·009	−δ·133	−δ·239	−δ·104	3	3	δ	δ	0
2	3000	75·16 Air 24·84 H	99·86	0·355	−0·564	−0·035	−0·599	−0·600	+0·226	10	4	0	0·15	1·5
3	3900	4·866 Air 95·134 H	49·91	0·132	+0·033	+0·002	+0·035	+0·070	+0·118	12	6	0·002	0·06	1·2
4	2900	78·295 Air 21·705 H	99·857	5·808	−0·535	−0·034	−0·569	−0·571	+0·525	34	12	0·03	0·11	1·65
5	2800	9·3 Air 90·8 H	86·385	7·244	+0·041	+0·003	+0·044	+0·05	+0·143	27	10	0·034	0·033	1·75
6	2300	1·798 Air 98·202 H	79·84	7·572	+0·043	+0·003	+0·046	+0·058	+0·075	23	8	0·008	0·033	2·85
7	2950	4·795 Air 95·205 H	74·98	9·654	+0·054	+0·004	+0·058	+0·078	+0·136	17	10	0·016	0·11	6·6
8	2650	67·75 Air 32·25 H	130·97	6·717	−0·571	−0·040	−0·611	−0·466	+0·383	12	6	0·01	0·07	2·6
9	3800	4·07 Air 95·93 H	100·72	6·781	+0·039	+0·002	+0·041	+0·041	+0·08	10	10	0·012	0·078	2·6
10	2700	58·29 Air 41·71 H	144·02	8·846	−0·504	−0·035	−0·539	−0·375	+0·317	8·5	8	0·011	0·07	3·6
11	1900	91·81 Air 8·19 H	152·67	7·406	−1·002	−0·069	−1·101	−0·721	+0·904	9	8	0	0·225	9·0
12	1760	97·56 Air 2·44 H	138·55	7·474	−1·032	−0·11	−1·142	−0·825	+0·814	13	8	0·001	0·053	8·2
13	3100	4·375 Air 95·625 H	87·74	88·66	+0·178	+0·011	+0·189	+0·215	+0·248	14	6	0·08	0·17	4·6
14	3300	6·08 Air 93·92 H	91·32	92·951	+0·081	+0·005	+0·086	+0·094	+0·132	18	8	0·157	0·07	3·2
15	3000	5·043 Air 94·957 H	73·99	90·353	+0·072	+0·005	+0·077	+0·104	+0·136	20	10	0·18	0·11	1·65
16	3000	2·99 Air 97·01 H	85·15	89·242	+0·111	+0·007	+0·118	+0·139	+0·159	42	15	0·472	0·44	3·2
17	2900	4·13 Air 95·87 H	104·72	89·858	+0·073	+0·004	+0·077	+0·073	+0·098	15·5	10	0·09	0·035	6·2
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

Remarks on the Tables.

The correction for conduction of heat through the plug, inserted in column 6 of Table I., and in column 7 of the rest of the Tables, was obtained from data furnished by experiments in which the difference between the temperature of the bath and the air was purposely made very great. It was considered as directly proportional to the difference of temperature, and inversely to the quantity of elastic fluid transmitted in a given time.

The 10th column of Tables II., III., IV., and V. is calculated on the hypothesis that, in mixtures with other gases, atmospheric air retains its thermal qualities without change. This hypothesis is almost certainly incorrect, since it is reasonable to expect that the effect of mixture on the physical character is experienced by each of the constituent gases. The column is given as one method of showing the effect of mixture.

Effect of Mixture on the Constituent Gases.—Although the experiments on nitrogen

given in Table III. are not so numerous as might be desired, we may infer from them, and the results in Table II., that common air and all other mixtures of oxygen and nitrogen behave more like a perfect gas, *i. e.* give less cooling effect than either one or the other gas alone. We might expect the mixture to be something intermediate between the two. But this does not appear to be the case. The two are very nearly equal in their deviations from the condition of a perfect gas. Nitrogen deviates less than oxygen, but oxygen mixed with nitrogen differs less than nitrogen!

In the case of carbonic acid, which at low temperatures (7°) deviates five times as much as atmospheric air, we might expect that a mixture of CO_2 and air would deviate more than air and less than CO_2. This is the case (see Table IV.). Further, we might expect the two to contribute each its proportion of cooling effect according to its own amount, and its specific heat volume for volume. But do the mixtures exhibit such a result? No! See column 10, Table IV., in which also note, under experiments 8 and 9, the great diminution produced by the admixture of hydrogen.

If, instead of attributing to air and carbonic acid moments in proportion to their specific heats, or 1 : 1·39, as we have done in column 10, we use 1 : ·7, we obtain more consistent results.

Let δ denote the cooling effect experienced by air per 100 inches of mercury, δ' that by carbonic acid, and Δ that by a mixture of volume V of air, and V′ of carbonic acid; then we may take

$$\Delta = \frac{m\mathrm{V}\delta + m'\mathrm{V}'\delta'}{m\mathrm{V} + m'\mathrm{V}'}$$

to represent the cooling effect for the mixture, where m and m' are numbers which we may call the moments (or importances) of the two in determining the cooling effect for the mixture. The ratio of m to m' is the proper result of each experiment on a mixture, if we knew with perfect accuracy the cooling effect for each gas with none of the other mixed. Now for common air we have direct experiments (Table I.), and know the cooling effect for it better than from any inferences from mixtures. But for pure CO_2 we know the effect, for the most part, only inferentially. Hence, having tried making $m : m' :: 1 : 1{\cdot}39$ without obtaining consistent results, we tried other proportions; and, after various attempts, found that $m : m' :: 1 : {\cdot}7$, for all temperatures and pressures within the limits of our experiments, gives results as consistent with one another as the probable errors of the experiments justify us in expecting. Thus, using the formula

$$\Delta = \frac{\mathrm{V}\delta + \mathrm{V}'\delta' \times {\cdot}7}{\mathrm{V} + \mathrm{V}' \times {\cdot}7},$$

we have, for calculating the effect for CO_2 from any experiment on a mixture, the following formula,

$$\delta' = \frac{(\mathrm{V} + \mathrm{V}' \times {\cdot}7)\Delta - \mathrm{V}\delta}{\mathrm{V}' \times {\cdot}7}.$$

Hence, using the numbers in columns 3 and 9 of Table IV. which relate to mixtures of air and carbonic acid alone, we find

TABLE VI.

No. of experiment.	Proportions of mixtures.		Temperature of bath.	Thermal effect for air.	Deduced thermal effect for pure CO_2.
	Air.	CO_2.	°	°	°
1	68·42	31·58	7·36	—·88	—4·51
2	89·16	10·84	7·36	—·88	—4·61
3	3·52	96·48	7·38	—·88	—4·46
4	62·5	37·5	7·41	—·88	—4·19
5	88·13	11·87	7·43	—·88	—3·98
6	97·46	2·54	7·61	—·88	—3·89
16	1·83	98·17	35·6	—·75	—3·44
14	67·7	32·3	49·7	—· 7	—3·04
15	87·77	12·23	49·76	—· 7	—2·77
13	0·83	99·17	54	—·66	—2·96
10	2·11	97·89	93·52	—·51	—2·19
11	56·78	43·22	91·26	—·51	—2·21
12	77·77	22·23	91·64	—·51	—3·08
17	1·66	98·34	97·55	—·49	—2·16
1	2		3	4	5

The agreement for each set of results at temperatures nearly agreeing (with one exception, No. 12), shows that the assumption $m : m' :: 1 : \cdot 7$ cannot be far wrong within our limits of temperature.

[Received subsequently to the reading of the Paper.]

Application of the preceding results to deduce approximately the Equation of Elasticity for the gases experimented on.

The "equation of elasticity" for any fluid is the most appropriate name for the equation expressing the relation between the pressure and the volume of any portion of the fluid. As this relation depends on the temperature, the equation expressing it involves essentially three variables, which, as in our previous communications on this subject, we shall denote by p, v, t. Of these, p is the pressure in units of force per unit of area, v the volume of a unit mass of the fluid, and t the temperature according to the absolute thermodynamic system of thermometry * which we have proposed. As before, we shall still adopt a degree, or thermometric unit, agreeing approximately with the degree Centigrade of the air-thermometer; according to which, as we have demonstrated by experiment †, the value of t for the freezing-point is within a few tenths of a degree of 273·7 (its value at the standard boiling-point being, by definition of the Centigrade scale, 100° more than at the freezing-point).

Instead of, as in our previous communications, taking v and t as independent variables, we shall now take p and t; and we shall accordingly consider the object of the equation of elasticity as being to express v explicitly as a function of p and t. Whatever may be the relation between these elements, the thermal effect, $d\mathfrak{H}$ (reckoned as positive when it is a rise in temperature), produced by forcing the fluid in a continuous stream through a narrow passage or porous plug by an infinitely small difference of pressures, dp, will

* Philosophical Transactions, 1854, p. 350. † Ibid. p. 352.

he given by the formula

$$\frac{d\vartheta}{dp} = -\frac{1}{JK}\left(t\frac{dv}{dt} - v\right),$$

where K denotes the thermal capacity, under constant pressure, of unit of mass of the fluid. This formula may be derived from equation (15.) of our previous communication already referred to, by substituting p, v, and $-\vartheta$ for P, V, and δ in that equation, changing to p and t, instead of v and t, as independent variables, and differentiating with reference to p. It is scarcely necessary to remark that a direct demonstration of our present formula, founded on elementary thermodynamic principles, may be readily obtained.

Each experiment, of the several series recorded above, gives a value for $\frac{d\vartheta}{dp}$, which is found by multiplying the "corrected thermal effect" by $\frac{\cdot 299218}{2114}$, to reduce from the amounts per 100 inches of mercury to the amounts per pound per square foot. Now by examining carefully the series of results for different temperatures, in the cases of atmospheric air and of carbonic acid, we find that they follow very closely the law of varying inversely as the square of the absolute temperature (or temperature Centigrade with 273·7 added). Thus for air the formula

$$^{\circ}\cdot 92 \times \left(\frac{273\cdot 7}{t}\right)^2$$

and for carbonic acid

$$4^{\circ}\cdot 64 \times \left(\frac{273\cdot 7}{t}\right)^2$$

express, the former almost accurately, the latter with a deviation which we shall hereafter investigate, the results through the whole range of temperature for which the investigation has been carried out.

Air.

Temperature.	Actual cooling effect.	Theoretical cooling effect.
°	°	°
0	·92	·92
7·1	·88	·87
39·5	·75	·70
92·8	·51	·51

Carbonic acid.

Temperature.	Actual cooling effect.	Theoretical cooling effect.
°	°	°
0	4·64	4·64
7·4	4·37	4·4
35·6	3·41	3·63
54·0	2·95	3·23
93·5	2·16	2·57
97·5	2·14	2·52

We have not experiments enough to establish the law of variation with temperature of the thermal effect for the pure gases oxygen and nitrogen, or for any stated mixture of them other than common air; but there can be no doubt, from the general character of the results, that the same law will be about as approximately followed by them as it is by air.

Hence we may presume that in all these cases the cooling effect is very well represented by the formula

$$\frac{-d\vartheta}{dp} = A\left(\frac{273{\cdot}7}{t}\right)^2.$$

Comparing this with the general formula given above, we find

$$t\frac{dv}{dt} - v = AJK\left(\frac{273{\cdot}7}{t}\right)^3.$$

The general integral of this differential equation, for v in terms of t, is

$$v = Pt - \tfrac{1}{2}AJK\left(\frac{273{\cdot}7}{t}\right)^2,$$

P denoting an arbitrary constant with reference to t, which, so far as this integration is concerned, may be an arbitrary function of p. To determine its form, we remark in the first place, in consequence of Boyle's law, that it must be approximately $\frac{C}{p}$, C being independent of both pressure and temperature; and thus, if we omit the second term, we have two gaseous laws expressed by the approximate equation

$$v = \frac{Ct}{p}.$$

Now it is generally believed that at higher and higher temperatures the gases approximate more and more nearly to the rigorous fulfilment of Boyle's law. If this is true, the complete expression for P must be of the form $\frac{C}{p}$, since any other would simply show deviation from Boyle's law at very high temperatures, when the second term of our general integral disappears. Assuming then that no such deviation exists, we have, as the complete solution,

$$v = \frac{Ct}{p} - \tfrac{1}{2}AJK\left(\frac{273{\cdot}7}{t}\right)^2 p.$$

This is an expression of exactly the same form as that which Professor Rankine found applicable to carbonic acid, in the first place to express its deviations from the laws of Boyle and Gay-Lussac, as shown by Regnault's experiments, and which he afterwards proved to give correctly the law and the absolute amount of the cooling effect demonstrated by our first experiments on that gas*.

That more complicated formulæ were found for the law of elasticity for common air both by Mr. Rankine and by ourselves, now seems to be owing to an irreconcileability among the data we had from observation. The whole amounts of the devia-

* Philosophical Transactions, 1854, Part II. p. 336.

tions from the gaseous laws are so small, for common air, that very small absolute errors in observations of so heterogeneous a character as those of REGNAULT on the law of compression and on the changes produced by pressure in the coefficients of expansion, and our own on the thermo-dynamic property on which we have experimented, may readily present us with results either absolutely inconsistent with one another, or only reconcileable by very strained assumptions. It is satisfactory now to find, when we have succeeded in extending our observations through a considerable range of temperature, that they lead to so simple a law; and it is probable that the formula we have been led to by these observations alone, will give the deviations from BOYLE'S law, and the changes produced by pressure in the coefficients of expansion, with more accuracy than has hitherto been attained in attempts to determine these deviations by direct observation. We must, however, reserve for a future communication the comparison between such results of our theory and experiments and REGNAULT'S direct observations. In the mean time we conclude by putting the integral equation of elasticity into a more convenient form, by taking $C=\frac{\mathfrak{h}}{t_0}$, where $\mathfrak{h}$ denotes the "height of the homogeneous atmosphere" for the gas under any excessively small pressure, at any temperature t_0, and taking t_0 to denote the absolute temperature of freezing water, in which case we shall have, as nearly as observations hitherto made allow us to determine,

$$t_0=273°{\cdot}7.$$

Then, in terms of this notation, and of that above explained, in which t, p, v denote absolute temperature, pressure in pounds weight per square foot, and volume in cubic feet of one pound of air, the equation of elasticity investigated above becomes

$$v=\frac{\mathfrak{h}t}{pt_0}-\tfrac{1}{3}\mathrm{AJK}\left(\frac{t_0}{t}\right)^3,$$

where A denotes the amount of the thermal effect per pound per square foot, determined by our observations, reckoned positive when it is a depression of temperature.

XXVI. *On the Law of Expansion of Superheated Steam.*

By WILLIAM FAIRBAIRN, *Esq., LL.D., F.R.S., and* THOMAS TATE, *Esq.*

Received March 20,—Read April 3, 1862.

THE following experiments have been undertaken to verify the law of expansion for superheated steam indicated in a previous paper*.

The earliest experiments on the subject were made by Mr. FROST in America, but without sufficient accuracy to be of scientific value. Mr. SIEMENS has also experimented on the expansion of steam isolated from water; his results give a much higher rate of expansion for steam than for ordinary gases; but, owing to the obvious defects of Mr. SIEMENS's method of conducting the experiments, we consider that his results are not reliable.

For gases, the rate of expansion is expressed by the formula, for constant volume,

$$\frac{P}{P_1}=\frac{E+t}{E+t_1}, \quad \ldots \ldots \ldots \ldots \ldots \quad (1.)$$

where E is a constant derived from experiment and determined by REGNAULT to be 459 in the case of air In the paper alluded to, it was shown that, with a certain proviso, the rate of expansion of superheated steam nearly coincided with that of air. Within a short distance of the maximum temperature of saturation, the rate of expansion of steam was found to be exceedingly variable; near the saturation-point it is higher than that of air, and it decreases as the temperature is increased until it becomes sensibly identical with that of air. The results on which this law was based were too limited in their range for much numerical accuracy in the constants deduced.

Hence it has been our object in the present paper to supply the deficiency in the previous one, by affording experimental data of the expansion of steam at higher temperatures and with a greater range of superheating than was possible with the apparatus employed in ascertaining the density of steam. The results obtained in these later researches, however, confirm the general law deduced from the previous ones.

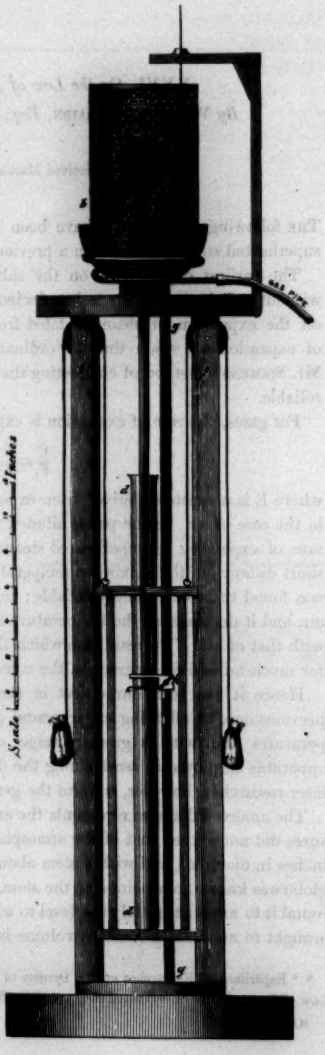
The annexed diagram represents the experimental apparatus employed where the pressures did not exceed that of the atmosphere. It consists of a glass globe *a*, about three inches in diameter, and with a stem about thirty-five inches long. The capacity of this globe was known to a point *b* on the stem, where a piece of fine platinum wire was twisted round it to mark accurately the level to which the mercury column in the stem was to be brought to maintain a constant volume in the globe. The stem dipped below into the

* "Experimental Researches on the Density of Steam at different Temperatures, and to determine the Law of Expansion of Superheated Steam," Phil. Trans. 1860, p. 185.

1½-inch tube *d*, which was supported on a frame of wood *e e*, sliding up and down vertically on the larger frame *f f*, on which the apparatus was supported. The frame *e e*, and the tube *d*, were balanced by cords passing over pulleys in the top of the frame, and weighted by bags filled with small pieces of iron. In this way the tube *d* could be adjusted with the greatest facility, so as to maintain the upper level of the mercury column at a constant position. To read the lower and variable level of the column, a rod *g g*, graduated into tenths of an inch, was fixed vertically, carrying a finger and vernier, *h*, which could be made to coincide accurately with the top of the meniscus of mercury, *c*.

For heating the globe, a glass bath, *k*, containing oil, was provided, fixed in an outer iron mercury bath, *l*. This was heated by a coil of gas-jets, and the oil was stirred continually, excepting at the instant of adjusting the upper level of the column to the level of the platinum wire. The globe was fixed in the oil-bath by a stuffing-box.

The method of conducting the experiments was as follows. The globe *a* was filled with dry and warm mercury, the air-bubbles being extracted from time to time by an air-pump. It was then inverted to form a Torricellian vacuum. A small glass globule of water was then inserted, the platinum wire fixed in its place, and an india-rubber cap fitted over the extremity of the stem. It was then transferred to its place in the oil-bath, and fixed there. The india-rubber cap was replaced by an open glass cistern, so that the glass tube *d* could be elevated to its position. The gas-jets were lighted, and the temperature raised to 300°. From this point the levels of the column were read off at intervals of 50° until the temperature of saturation was reached. The levels were



taken in a series of descending temperatures, to avoid the influence of steam boiling out of the mercury as the temperature rose, and to eliminate the effect of the cohesion of the glass on the water, as explained in our previous paper on the Density of Steam.

Capacity of the Globe.

Twelve cubic inches of mercury were measured into the globe, and a file-mark made on the stem.

Below the first file-mark, at a distance of 14·45 inches, another file-mark was made to afford a fixed point for ascertaining the correspondence of the upper file-mark with the readings on the fixed graduated rod or cathetometer.

Correction of Readings.

Let a be the reading on the fixed rod of the level of the column; b be the reading of the lower file-mark on the globe-stem. Then

$+b-a$=the height of the column of mercury in the globe-stem.

To correct this for temperature, $7\frac{1}{2}$ inches of mercury, included in the oil-bath and its stuffing-box, were corrected for the temperature of the oil, and the remainder for the temperature of the atmosphere at the time.

By deducting the column so corrected from the reading of the barometer at the time, the total pressure in the globe is obtained.

The readings of the thermometer are corrected for the portion out of the oil-bath.

The pressure of the vapour of mercury is calculated from data supplied with great courtesy by M. Regnault, and embodying the results of unpublished experiments. The pressure of this vapour is assumed to be the same as that in a vacuum, as the vapour in the globe remains still for a sufficient time (it is believed) for saturation to take place. In this view we have been strengthened by M. Regnault's opinion.

By deducting the pressure of mercury vapour from the total pressure in the globe, the pressure of the steam is obtained.

Experiment I.

0·285 grain of water introduced into globe.

Time.	Temperature in oil-bath, Fahr.	Cathetometer, in inches.	Column of mercury, in inches.	Temperature of air, Fahr.	Remarks.
h m	°			°	
4 46	250	10·96	25·57	58	Barometer read 30·33 inches, or, corrected to 32° F., 30·27 in.
4 55	250	10·96	25·57		The lower file-mark read 22·08 inches on the cathetometer.
5 8	300	11·40	25·13		
5 14	300	11·38	25·15		
5 17	300	11·40	25·13		
5 20	300	11·40	25·13		
5 37	250	10·97	25·56		
5 40	250	10·96	25·57		
6 0	200	10·63	25·90		
6 8	200	10·60	25·93		
6 13	200	10·60	25·93		
6 45	150	10·28	26·25		
6 50	150	10·25	26·28		
7 25	100	7·90	28·63		Barometer read 30·36 inches, or, corrected to 32° F., 30·30 inches.
7 30	100	7·87	28·66	57	

Summary of Results.

Temperature, Fahr.	Mean column of mercury, in inches.	Mean column corrected to 32°.	Total pressure in globe, in inches.	Volume of globe corrected for expansion of glass, in grs. of water.	Pressure of vapour of mercury, in inches.	Pressure of steam, in inches.	Value of E.
302°88	25·13	24·89	5·38	3045·5	0·1736	5·21	474·48
251·64	25·55	25·34	4·94	3043·4	0·066	4·87	450·11
200·74	25·92	25·75	4·54	3041·2	0·024	4·52	428·88
150·18	26·26	26·13	4·17	3039·1	0·008	4·16	
100·00	28·64	28·54	1·76	3037·0	0·003	1·76	

Experiment II.

0·405 grain of water introduced into globe.

Time.	Temperature in oil-bath, Fahr.	Cathetometer, in inches.	Column of mercury, in inches.	Temperature of air, Fahr.	Remarks.
h m					
4 30	300°	13·43	23·16	59°	Barometer read 30·38 inches throughout the experiment, or, corrected to 32° F., 30·31 inches. Lower file-mark read 22·14 inches on the cathetometer.
4 40	300	13·45	23·14		
4 45	302	13·50	23·09		
4 50	300	13·49	23·10		
5 10	250	12·90	23·69		
5 16	250	12·90	23·69		
5 20	250	12·90	23·69		
5 40	200	12·43	24·16	60	
5 45	200	12·43	24·16		
5 50	200	12·43	24·16		
6 10	150	11·94	24·65		
6 15	150	11·98	24·61		
6 20	150	11·97	24·62		
6 25	150	11·97	24·62		

Summary of Results.

Temperature, Fahr., corrected.	Mean column of mercury, in inches.	Mean column corrected to 32°.	Total pressure in globe, in inches.	Volume of globe corrected for expansion of glass, in grs. of water.	Pressure of vapour of mercury, in inches.	Pressure of steam, in inches.	Value of E.
302°88	23·11	22·87	7·44	3045·5	0·174	7·27	455·57
251·64	23·69	23·49	6·82	3043·4	0·066	6·75	
200·74	24·16	23·99	6·32	3041·2	0·024	6·30	
150·18	24·62	24·49	5·82	3039·1	0·008	5·81	443·86

In the readings at 251·64 some error seems to have crept in. In deducing E, the readings at 302·88 and 200·74 are therefore taken.

Experiment III.

0·545 grain of water introduced into globe.

Time.	Temperature of oil-bath, Fahr.	Cathetometer, in inches.	Column of mercury, in inches.	Temperature of air, Fahr.	Remarks.
h m	°			°	
3 55	299	16·05	20·26	59	Barometer read 30·13 inches, or, corrected to 32° F., 30·06 inches throughout the experiment.
4 0	300	16·05	20·26		
4 5	300	16·05	20·26		Lower file-mark read 21·86 inches on the cathetometer.
4 33	250	15·33	20·98		
4 40	250	15·32	20·99	60	
4 45	250	15·34	20·97		
5 3	200	14·66	21·65		
5 10	200	14·66	21·65		
5 14	200	14·65	21·66	61	
5 32	150	13·05	23·26	.....	Condensation in globe.
5 37	150	13·10	23·21		
5 43	150	13·05	23·26		

Summary of Results.

Temperature, Fahr., corrected.	Mean column of mercury, in inches.	Mean column, corrected to 32°.	Total pressure in globe, in inches.	Volume of globe corrected for expansion of glass, in grs. of water.	Pressure of vapour of mercury, in inches.	Pressure of steam, in inches.	Value of E.
302°88	20·26	20·03	10·03	3045·5	0·174	9·86	466·85
251·64	20·98	20·78	9·28	3043·4	0·066	9·21	451·94
200·74	21·65	21·49	8·57	3041·2	0·024	8·55	109·74
150·18	23·25	23·12	6·94	3039·1	0·008	6·93	

Experiment IV.

0·53 grain of water introduced into globe.

Time.	Temperature in oil-bath, Fahr.	Cathetometer, in inches.	Column of mercury, in inches.	Temperature of air, Fahr.	Remarks.
h m	°			°	
12 0	300	16·62	20·63	65	Barometer read 30·17 to 30·18 inches during experiment, the corrected reading being 30·09 inches.
12 5	300	16·62	20·63		
12 15	300	16·61	20·64		Lower file-mark read 22·80 inches on the cathetometer.
12 44	250	15·93	21·32	65	
12 51	250	15·92	21·33		
1 5	250	15·92	21·33		
1 38	200	15·27	21·98		
1 45	200	15·28	21·97		
1 52	200	15·28	21·97	66	
2 35	150	13·95	23·30		
2 47	150	14·00	23·25		
3 0	150	14·01	23·24		
3 5	150	14·00	23·25		
3 20	165	14·80	22·45		
3 23	165	14·79	22·46	67	

Summary of Results.

Temperature, Fahr., corrected.	Mean column of mercury, in inches.	Mean column, corrected to 32°.	Total pressure in globe, in inches.	Volume of globe corrected for expansion of glass, in grs. of water.	Pressure of vapour of mercury, in inches.	Pressure of steam, in inches.	Value of E.
302·88	20·63	20·39	9·70	3045·5	0·174	9·53	
251·64	21·33	21·12	8·97	3043·4	0·066	8·90	464·83
200·74	21·97	21·80	8·29	3041·2	0·024	8·27	460·79
165·45	22·46	22·31	7·78	3039·7	0·011	7·77	378·33
150·18	23·25	23·11	6·98	3039·1	0·008	6·97	

Experiment V.

0·875 grain of water introduced into globe.

Time.	Temperature in oil-bath, Fahr.	Cathetometer, in inches.	Column of mercury, in inches.	Temperature of air, Fahr.	Remarks.
h m					
1 10	300	23·25	14·03	63·5	Barometer read 30·13 inches, or, corrected to 32° F., 30·06 inches.
1 15	301	23·27	14·01		
1 20	300	23·26	14·02		Lower file-mark read 22·63 inches on the cathetometer.
1 25	300	23·25	14·03		
1 45	250	22·14	15·14		
1 50	250	22·11	15·17		
2 0	250	22·14	15·14		
2 5	250	22·13	15·15		
2 35	200	21·00	16·28		
2 41	200	21·00	16·28		
2 45	200	21·01	16·27	63·5	
2 50	200	21·00	16·28		
3 5	180	20·50	16·78		
3 15	180	20·49	16·79		
3 20	180	20·49	16·79	64·0	
3 35	165	17·27	20·01		
3 45	167	17·85			
3 50	165	17·32	19·96		
4 0	165	17·30	19·98		

Summary of Results.

Temperature, Fahr., corrected.	Mean column of mercury, in inches.	Mean column, corrected to 32°.	Total pressure in globe, in inches.	Volume of globe corrected for expansion of glass, in grs. of water.	Pressure of vapour of mercury, in inches.	Pressure of steam, in inches.	Value of E.
165·45	19·98	19·84	10·22	3039·7	0·011	10·21	
180·72	16·79	16·65	13·41	3040·6	0·016	13·39	
200·74	16·28	16·13	13·93	3041·2	0·024	13·91	
251·64	15·15	14·97	15·09	3043·4	0·066	15·02	430·90
302·88	14·02	13·80	16·26	3045·5	0·174	16·09	460·28

Summary of Results.

The law of expansion of gaseous bodies is expressed by the formula

$$\frac{E+t}{E+t_1}=\frac{PV}{P_1V_1},$$

$$\therefore E=\frac{PVt_1-P_1V_1t}{P_1V_1-PV},$$

where E is a constant. The values of E thus deduced have been placed in the last column of the foregoing Tables. They show a decreasing rate of expansion from the saturation-point upwards until (at a certain increase of temperature) the rate of expansion coincides with that of a perfect gas.

Taking from the preceding Tables the two results, which in each case represent the rate of expansion at the greatest distance from the saturation-point, we have the following values of E:—

(1)	474·48
	450·11
(2)	455·57
	443·86
(3)	466·85
	451·94
(4)	464·83
	460·79
(5)	460·28
	9)4128·71
Mean value of E=	458·74

The value of E for air, as ascertained by REGNAULT, is 459. That assumed for a perfect gas by RANKINE is 461·2.

Hence the conclusion which we suggested in our previous paper has been satisfactorily demonstrated in more carefully conducted experiments, and the rate of expansion of superheated steam is shown to be almost identical with that of air and other permanent gases, if calculated at temperatures not too close to the maximum temperature of saturation.

XXVII. *On the Long Spectrum of Electric Light.* By G. G. Stokes, *M.A., D.C.L., Sec. R.S., Lucasian Professor of Mathematics in the University of Cambridge.*

Received June 19,—Read June 19, 1862.

Introduction.

The experimental researches described in a former paper * led me indirectly to the conclusion that the electric spark, whether obtained directly from the prime conductor of an ordinary electrifying machine, or from the discharge of a Leyden jar, emits rays of very high refrangibility, surpassing in this respect any that reach us from the sun—and that these rays pass freely through quartz, while glass absorbs them, as it does also the most refrangible of the solar rays. I was induced in consequence to procure prisms and a lens of quartz, which were applied in the first instance to the examination of the solar spectrum, and which immediately revealed the existence of an invisible region extending as far beyond that previously known as the latter extends beyond the visible spectrum, and exhibiting a continuation of Fraunhofer's lines †. A map of the new lines was exhibited at an evening lecture delivered before the British Association at their Meeting in Belfast in the autumn of the same year; and I then stated that I conceived we had obtained evidence that the limit of the solar spectrum in the more refrangible direction had been reached. In fact, the very same arrangement which revealed, by means of fluorescence, the existence of what were evidently rays of higher refrangibility coming from the electric spark failed to show anything of the kind when applied to the solar spectrum. At least, the only link in the chain of evidence which remained to be supplied by direct experiment related to the reflecting power, for rays of high refrangibility, of the metallic speculum of the heliostat which was employed to reflect the sun's rays into a convenient direction; and this was shortly afterwards tested by direct experiment, on rays from an electric discharge separated by prismatic refraction.

In making preparations for a lecture on the subject delivered at the Royal Institution in February 1853, in which I had the benefit of the kind assistance of Mr. Faraday, recourse was naturally had to electric light, on account of the extraordinary richness which it had been found to possess in rays of high refrangibility. Although fully prepared to expect rays of much higher refrangibility than were found in the solar spectrum, I was perfectly astonished, on subjecting a powerful discharge from a Leyden jar to prismatic analysis with quartz apparatus, to find a spectrum extending no less than six or eight times the length of the visible spectrum, and could not help at first suspecting that it was a mistake arising from the reflexion of stray light. A similarly extensive

* "On the Change of Refrangibility of Light," Phil. Trans. for 1852, p. 463. † Ibid. p. 559.

spectrum was obtained from the voltaic arc, and this was sufficiently bright to be exhibited to the audience, the arc passing between copper electrodes, and the pure spectrum formed by quartz apparatus being received on a piece of uranium glass cut for the purpose. The spectrum thus formed was found to consist entirely of bright lines *, whereas the spectrum of the discharge of a Leyden jar had appeared (perhaps from not having been truly in focus) to be continuous, or at least not wholly discontinuous.

The mode of absorption of light by coloured solutions, as observed by the prism, affords in many cases most valuable characters of particular substances, which, strange to say, though so easily observed, have till very lately been almost wholly neglected by chemists. Having obtained the long spectrum above mentioned, I could not fail to be interested with the manner in which substances, especially pure but otherwise imperfectly known organic substances, might behave as to their absorption of the rays of high refrangibility. But the difficulties attending the habitual use of a nitric-acid battery of 30 or 40 cells deterred me from entering on this investigation, and I determined to confine myself to the solar spectrum.

On account of some inconvenience attending the tarnishing of the speculum of my heliostat, I was induced to order a quartz plate, intended to be either silvered or coated with the usual amalgam of tin. On trying on a small scale the reflecting power of such plates with respect to the invisible rays, which may be done by means of fluorescence almost as easily as if those rays were visible †, I noticed a remarkable falling off in the reflecting power of the silvered plate for the most refrangible of the solar rays, which I readily found was due to a peculiarity of the metal silver. This metal is highly reflective for the invisible as it is for the visible rays up to about the fixed line S‡, when its reflecting power falls off, with remarkable rapidity, and for the more refrangible rays of the solar spectrum is comparable with that of a vitreous substance rather than with that of a metal. Steel, gold, tin, &c. showed nothing of the kind, but copiously reflected the invisible rays.

A few years ago, as Dr. ROBINSON was showing me some experiments with the induction coil, it seemed worth while to try whether the spark obtained when a Leyden jar has its coatings connected with the secondary terminals might not be sufficiently strong to exhibit by projection the long spectrum shown by electric light. On projecting a spectrum formed by a prism and lens of quartz on a piece of uranium glass, the long spectrum was in fact exhibited. It was not, indeed, so bright as when formed by means of a powerful voltaic battery, but nevertheless was quite bright enough to work by. It was discontinuous, consisting of bright lines. On changing the metals between which the spark passed, we found that the lines were changed, which showed clearly that they were due to the particular metals.

* Proceedings of the Royal Institution, vol. i. p. 264. † Philosophical Transactions for 1852, p. 537.

‡ According to the notation employed in the Map published in the Philosophical Transactions for 1859, Plate XLVII. In this Plate the group S should have been represented as three lines, of which the middle (specially named S) divides the interval between the 1st and 3rd in the proportion of 3 to 2 nearly, the spaces between the lines being a little darkened by shading.

A wide field of research was thus thrown open to any one taking the very moderate trouble attending the use of an induction coil. It remained to study the lines given by different metals and gases, and the absorbing action of various substances with respect to the invisible rays of different refrangibilities.

Various observations were made from time to time in this subject. As regards the metallic lines, it is perfectly easy to view them at pleasure; but to obtain faithful delineations of them is another matter. Even an accomplished artist would find difficulty in obtaining by mere eye-sketching a faithful representation of an object which requires to be seen in the dark. I tried different methods without being able to satisfy myself as to the accuracy of the drawings which could be thus obtained, and frequently thought of resorting to photography.

Meanwhile the mode of absorption of the rays of high refrangibility by a good number of substances was observed. Nothing is easier, to a person provided with a cell with parallel faces of quartz, than to observe by means of fluorescence the mode of absorption of these rays by a given solution; but to draw safe conclusions as to the optical character in this respect of the substance deemed to be in solution is not so easy as it might appear; for the rays of high refrangibility are liable to be absorbed by an exceedingly small amount of an impurity which may chance to be present without the observer's knowledge. Thus I found that about a quarter of a square inch of clean filtering paper sufficiently contaminated the water contained in a small cell to interfere sensibly with its transparency. Should the solution be transparent there would be no difficulty, for the effect of an impurity would not be to render transparent a solution which otherwise would be opaque. Should it, on the other hand, absorb the invisible rays, or some of them, with great energy, or in a peculiar manner, we might again conclude that we had obtained the true character of the substance deemed to be observed. The most remarkable example of this kind which I met with among inorganic colourless solutions was in the case of nitric acid and its salts, such as nitrate of potash, soda, ammonia, baryta, which absorb the rays of high refrangibility with great energy and in a peculiar manner, exhibiting a maximum of opacity followed by a maximum of transparency, beyond which the absorption becomes still more energetic than before. But if the solution should be found to absorb the rays of high refrangibility with only moderate energy, it would be left doubtful whether the observed absorption might not be due to some impurity; and I did not see how this doubt could be solved otherwise than by a laborious system of recrystallizations.

After having obtained these results, I found by conversation with my friend Dr. Miller that he also had been engaged at the same subject, working by photography, and had prepared a number of photographs of metallic spectra, and studied by the same means the absorption of the rays of high refrangibility by a great variety of substances, chiefly inorganic acids, bases, and salts, and the commoner organic bodies. Although a large part of the task which I had proposed to myself has thus been accomplished in another way, there are many results which I have met with which are not

likely to have been obtained by one working by photography, and I have therefore thought it well to draw up a paper embodying these results, and thus forming, as it were, a supplement to the paper by Dr. MILLER.

Preparation of a Screen by means of a Salt of Uranium.

Few substances are more powerfully fluorescent than several of the salts of sesquioxide of uranium; and a piece of glass coloured by uranium and polished along at least two planes at right angles to each other is exceedingly convenient, from its powerful fluorescence and its permanence, for a screen on which to receive a spectrum. Nevertheless such a screen, which must be viewed in particular directions in order to get the strongest effect, is in many cases less convenient than a screen would be which was prepared by means of a highly fluorescent powder treated like a water colour, which could be viewed in all directions indifferently. This is especially the case in taking measures by a method which will be mentioned presently. Besides, I find an excellent piece of such glass defective in fluorescent power as regards the extreme lines shown by aluminium; and some specimens are defective to a much greater extent, which is doubtless due to impurities. Accordingly I have long regarded it as a desideratum to obtain by precipitation an insoluble or very sparingly soluble salt of sesquioxide of uranium which should be as fluorescent as the best salts of that base, and which might be treated like a water colour. I have now succeeded in preparing such a salt, though not by direct precipitation.

The ordinary phosphate obtained by precipitation, the composition of which, independently of water of hydration, is $PO_4(U_2O_3)_2HO$, is only slightly fluorescent. If, however, this salt, with as much water as remains when it is washed by decantation, be put into a saucer, a little free phosphoric or sulphuric acid added, and then crystals of phosphate of soda, phosphate of ammonia, microcosmic salt, or borax be added in excess, the original salt is gradually changed into one which is powerfully fluorescent. The change seems to take place most rapidly with borax; but as an excess of this salt is liable slowly to decompose the fluorescent salt first formed, it is better to employ a phosphate. The quantity of acid should be sufficient to leave a decided acid reaction when the liquid is fully saturated by the alkaline phosphate employed. The change may be watched by observing from time to time the fluorescence of the salt by daylight, with the aid of absorbing media. It is complete in a few days at furthest, when the salt is ready to be collected.

This requires precaution, as the salt is quickly decomposed by dilute acids (and accordingly by its own mother-liquor if diluted), and even, though more slowly, by pure water, with the formation apparently of the original phosphate. It is also decomposed, at least in time, by alkaline carbonates, with the formation of a beautiful yellow non-fluorescent salt resembling the precipitate given by alkaline carbonates in salts of sesquioxide of uranium. The salt may be collected by adding at once, instead of water, a saturated solution of borax, in quantity at least sufficient to destroy the acid reaction.

The salt is then poured off in suspension from any undissolved crystals of the alkaline phosphate employed, and collected on a filter. A pressed cake of this salt, or a porous tile on which the salt is spread, having been moistened with a solution of borax, forms an admirable screen, and is what I have chiefly employed of late. It shows, of course, the visible as well as the invisible rays—the former by ordinary scattering, the latter by fluorescence.

From the circumstances of its formation, the salt is probably (abstraction being made of the water of hydration) the original phosphate with the equivalent of constitutional water replaced by an equivalent of an alkali, which would make it analogous to the highly fluorescent natural yellow uranite. At any rate this hypothesis guides us to its successful preparation, the conditions of which it would not have been easy to make out by observation alone. Without the use of free acid the fluorescence is not fully developed, which is accounted for by the insolubility of the original phosphate and the fluorescent salt, which presents an obstacle to the complete conversion of the one into the other.

Metallic Lines.

These may be viewed, as already mentioned, by passing the spark of an induction coil between two electrodes formed of the metal to be examined (the secondary terminals being respectively in connexion with the coatings of a jar of suitable size), forming a pure spectrum by a prism and lens of quartz, the faces of the prism being equally inclined to the axis of the crystal, and the lens being cut perpendicular to the axis, and receiving the spectrum on a suitable screen, for which, if a fluorescent liquid be employed, it is to be placed in a quartz-faced vessel, in default of which a piece of filtering paper may be saturated with the liquid.

If the visible spectrum and the very beginning of the invisible be excepted, the lines thus seen vary from metal to metal, and therefore are to be referred to the metal and not to the air. They are further distinguished from air lines by being formed only at an almost insensible distance from the tips of the electrodes, whereas air lines would extend right across. The spectrum is far too extended to allow us to regard the whole at once as in the position of minimum deviation; and if the prism be placed at all near the electrodes, without which we should have comparatively little light to work with, the effect of the different divergency, converted by the lens into convergency, of the rays in the primary and secondary planes is very great. In order to obtain a pure spectrum, the screen must be in focus as regards the primary plane; and if a particular point P of the spectrum be at a minimum deviation, the lines immediately about P are reduced almost to points, which are the images, for light of that refrangibility, of the tips of the electrodes, or, to speak more exactly, of the part of the spark just outside the tips. But in the secondary plane the rays on one side of P have not yet reached their focus, and on the other side have passed it; so that the image of a point is a line, the primary focal line, of a length increasing on receding from P in either direction, and accordingly the spectral image of either tip, assumed to be a mere point, would be a pair of slender

triangles vertically opposite, and having their common vertex at P, their lengths lying in the plane of refraction. The invisible spectrum is in fact made up of two such pairs of triangles corresponding to the two tips respectively, as may be readily seen when the electrodes are not too close. At a distance from P at which the length of the primary focal line becomes equal to that of the image of the spark, the two lines which are the images, for rays of the refrangibility answering to that distance, of the tips of the electrodes meet in the middle of the spectrum, and beyond that distance they overlap, so that a line appears to run across the spectrum, though it relates to rays which emanated only from the immediate neighbourhood of the tips of the electrodes, as may be seen by turning the prism till that part of the spectrum is at a minimum deviation, and focusing afresh.

Besides the bright lines, evidently due to metals, which have been mentioned, other weaker light is perceptible, too faint for precise observation. A portion of this is probably due to the air.

The chief part of the visible spectrum as seen by projection appears plainly to belong to the air; for the lines stretch across the interval separating the electrodes, while the lines belonging to the metals extend but a little way, even in the visible spectrum, and the former reappear when the electrodes are changed. With some metals, however, lines belonging to the metal appear in the visible spectrum which are comparable in strength with the invisible lines of high refrangibility; but in general it is rather remarkable how poor is the visible spectrum, and even the invisible region for a good distance beyond, compared with the part of the spectrum of still higher refrangibility, with respect to strong lines characteristic of the metal.

I have lately adopted a mode of laying down positions in the invisible spectrum which is extremely simple and convenient, and yields results agreeing well with one another. It might be applied to the formation of maps of the metallic lines; but this is unnecessary, as the subject has been worked out by Dr. Miller. It is still useful, however, for laying down the positions of bands of absorption, being more convenient and exact than estimating their place with reference to the known metallic lines.

The method is as follows. The quartz prism is placed on a block, raising it to a convenient height above a long drawing-board, to which the block is screwed, and is fixed at pleasure by a screw pressing upon it from above. The lens is fixed in a blackened board screwed edgeways to the drawing-board near the prism, so as to be ready to receive the rays of all refrangibilities after refraction through the prism. The focal length of the lens actually used was about 12 inches, and its diameter $1\frac{1}{4}$ inch. A convenient distance of the spark from the prism having been selected (I chose 30 inches), the drawing-board was turned round till it attained such a position that, on placing the prism in the position of minimum deviation for the middle of the long spectrum, the rays belonging to that part fell perpendicularly, or nearly so, on the lens, which had previously been placed so that this should be a convenient position relatively to the drawing-board. The prism was then fixed by its screw, and to mark the angle of incidence a pin was placed at the edge of the shadow of one of the blocks. On account of

the increasing refraction by the lens of rays of increasing refrangibility, the locus of the foci of the different rays formed an arc of a curve, or nearly a straight line, lying very obliquely to the axes of the pencils coming through the lens. The projection of this line on the board having been marked, a line was drawn bisecting this at right angles, and at a point in the latter line situated 11¾ inches from the former*, the board was pierced for the insertion of a pivot, which carried two wooden rulers, which could be clamped together at any convenient angle. The shorter of these carried a vertical needle, which as the ruler was turned moved in front of the focus of the different rays at the distance of about a quarter of an inch. The longer ruler carried a pricker, destined to mark on a sheet of paper, temporarily fastened to the drawing-board, the position of any object observed. Thus the prism, the lens, the axis of motion of the needle and pricker, and the pin for fixing the angle of incidence retained an invariable relative position when the drawing-board was moved. In observing, the electrodes were placed at the proper distance, and the board turned till the edge of the shadow fell on the pin. The rulers were then turned together till any bright line or other object was eclipsed by the needle, and its place was then pricked down. To obtain a fixed point of reference, I generally pricked down the position of the extreme red visible on a screen, such as a piece of paper; but if great accuracy were required, it might be better to employ a well-marked green air line.

The metals the spectra of which I have observed are Platinum, Palladium, Gold, Silver, Mercury, Antimony, Bismuth, Copper, Lead, Tin, Nickel, Cobalt, Iron, Cadmium, Zinc, Aluminium, Magnesium. Several of these show invisible lines of extraordinary strength, which is especially the case with zinc, cadmium, magnesium, aluminium, and lead, which last, in a spectrum not generally remarkable, contains one line surpassing perhaps all the other metals. Other metals exhibit lines which in certain parts of the spectrum are both bright and numerous; so that, in taking a rough view of the whole, certain parts of the spectrum are bright and tolerably continuous, while other parts are comparatively weak. This grouping of the lines is especially remarkable in copper, nickel, cobalt, iron, and tin. Of the metals mentioned, magnesium gives by far the shortest spectrum, ending in a very bright line, beyond which, however, excessively faint light may be perceived to a distance about as great as the extent of the longer spectra. Aluminium, on the other hand, stands at the head of the above metals for richness in rays of the very highest refrangibility; and it is to this part of the spectrum that the strong lines above mentioned belong. In calling these lines strong, it must be understood that some allowance is made for their very high refrangibility; for when observed as above described they do not appear *absolutely* quite so strong as the bold lines of zinc or cadmium. This is partly due to the defective transparency of quartz, which for this part of the spectrum shows itself by no means perfect; and indeed the highest aluminium line, which is a double line, can only be seen by rays which pass through the prism near its edge.

* A longer distance would have been better.

The following figure exhibits the principal lines of aluminium, with zinc and cadmium for comparison. In the first of the aluminium lines represented, I could not make out the division into two parts corresponding to the tips of the electrodes. R denotes the extreme red visible on a screen; the lines in the visible spectrum are omitted, as this

Fig. 1.

has been made the subject of elaborate researches by others. The horizontal distances are proportional to the distances of the several pricks from that belonging to the extreme red, and therefore vary as the chords of the arcs described by the pricker. This tends to correct to a certain extent the exaggeration of the more refrangible end of the spectrum arising from the mode adopted of laying down the positions of the lines. The lowest row of lines in the figure, which is placed here for the sake of comparison, will be referred to further on.

Besides the lens above mentioned, I sometimes employ in a different manner another of $\frac{1}{2}$ inch diameter and $2\frac{1}{2}$ inches focal length, and accordingly large for its focal length. This is used for forming an image of the spark, which is received on the substance that is to be examined, or that is used for examining the spark. The difference of focal length for the different rays is so enormous that, while one part of the spectrum is in focus, other parts are utterly out of focus, and thus we may judge in a general way of the refrangibility of the rays by which any particular effect is produced. In this way such concentration of the rays is obtained, that effects may be studied which would not bear examination by prismatic analysis. In speaking of this lens I shall call it the 2·5-inch lens, from its focal length.

Absorption of the invisible rays by Alkaloids, Glucosides, &c.

Before examining these substances it is requisite to dissolve them, and we must first inquire into the transparency of the solvent. Fortunately the most useful of all solvents, water, is transparent when pure; and as to reagents, we may employ sulphuric or hydrochloric acid for an acid, these acids being transparent, and ammonia, suppose, for an alkali. In speaking of a substance as transparent, I wish it only to be understood that it is of a transparency comparable with quartz. As to ammonia, although it absorbs the more refrangible rays when in quantity (unless the observed absorption were due to some impurity), it may be deemed transparent in the small quantity which alone it is

requisite to employ. Even alcohol, which in the state in which it is to be had is defective in transparency, is sufficiently transparent to be employed as a solvent for such substances as those under consideration, provided it be used in small thickness only.

The alkaloids and glucosides which I have examined are almost without exception intensely opaque for a portion at least of the invisible rays, absorbing them with an energy comparable for the most part to that with which colouring matters (such as alizarine, &c.) absorb the visible rays. The mode of absorption also is frequently, I might almost say generally, highly characteristic; so that by this single property they might be distinguished one from another. It frequently happens too that the mode of absorption decidedly changes according as the solution is acid or alkaline, which assists still further in the discrimination.

In the examination I sometimes employ a small cell with parallel faces of quartz, sometimes a wedge-shaped vessel, having its inclined faces also of quartz, but more commonly the former. The cell being filled with the solvent, a minute quantity of the substance is introduced, and the progress of the absorption is watched as the substance gradually dissolves, the fluid meantime being of course stirred up. In this way it is easy to seize the most characteristic phase of the absorption, which may be then registered by the pricking instrument. When minima of opacity occur, it is best to seize that stage of the absorption at which they are well developed. When no minima occur, a greater or less part of the more refrangible region is quickly absorbed, after which the absorption creeps on towards the less refrangible side. When once it has become tolerably stationary, the limit of the rays transmitted may be marked. It seems desirable not to go beyond this point in the absorption, lest some possible impurity in the substance examined, which if it had formed the whole of the specimen would have absorbed rays of lower refrangibility, should begin to make itself perceived, and its mode of absorption should be mistaken for that of the substance professed to be examined.

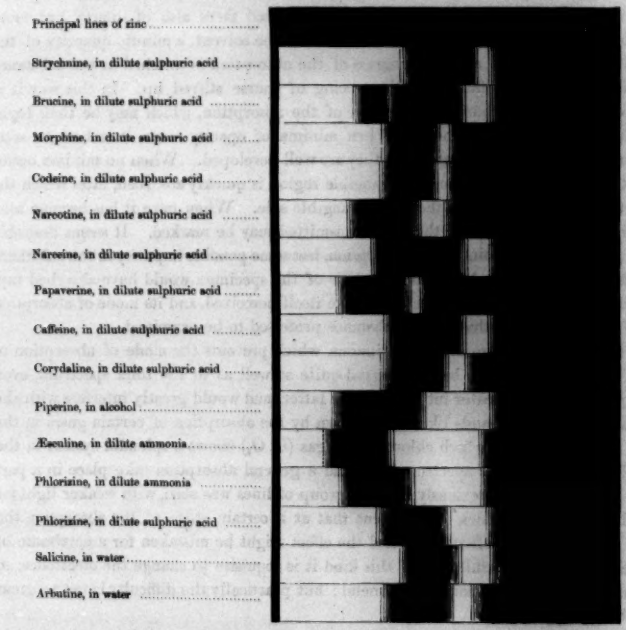
All the metallic spectra are discontinuous, which prevents the mode of absorption of even a solid or liquid from being observed quite so well as in the solar spectrum, even independently of the greater intensity of the latter, and would greatly interfere with the observation of narrow bands like those shown by the absorption of certain gases in the visible spectrum, and of which chlorous acid gas ($Cl\,O_4$) shows a splendid system in the invisible part of the solar spectrum. Should a general absorption take place in a part of the spectrum where previously a bright group of lines was seen, with weaker light for some distance on both sides, it is evident that at a certain stage of the absorption the bright group would be left isolated, and the effect might be mistaken for a maximum of transparency. In doubtful cases of this kind it is requisite to change the electrodes, so as to use the spectrum of some other metal; but practically the difficulty is not so great as might be supposed.

It is desirable to choose a metal which gives a spectrum that is bright and tolerably continuous in the region in which the distinctive features of the absorption are most likely to occur. For general use in the examination of substances such as here consi-

dered, I prefer tin—the electrodes (or one of them at least) being broad, for a reason which will be mentioned presently. Tin, indeed, is weak in the most refrangible region, though after a long interval of weakness it shows one pretty strong line between the 2nd and 3rd of the strong aluminium lines; but with these substances the distinctive features of the absorption hardly ever occur so late. For combined strength and continuity, copper answers well for the highly refrangible region in which tin is weak; while mercury, which may be employed in the form of amalgamated zinc, is the richest metal for the invisible region just beyond the visible spectrum; but I have employed tin almost exclusively.

The following figure gives the bands of absorption observed in solutions of several

Fig. 2.


Principal lines of zinc
Strychnine, in dilute sulphuric acid
Brucine, in dilute sulphuric acid
Morphine, in dilute sulphuric acid
Codeine, in dilute sulphuric acid
Narcotine, in dilute sulphuric acid
Narceine, in dilute sulphuric acid
Papaverine, in dilute sulphuric acid
Caffeine, in dilute sulphuric acid
Corydaline, in dilute sulphuric acid
Piperine, in alcohol
Æsculine, in dilute ammonia
Phlorizine, in dilute ammonia
Phlorizine, in dilute sulphuric acid
Salicine, in water
Arbutine, in water

alkaloids and glucosides. The bold lines of zinc are given as points of reference; but the observations were made with electrodes of tin. The border on the left is the limit of the red light visible on a screen.

Although the central part of the maxima of transparency in this figure is generally left white to save trouble, the reader must not suppose that that part of the spectrum suffers no absorption. On the contrary, it is more or less weakened when the solution has the strength to which the figure corresponds, and disappears altogether when the quantity of substance in solution is increased, while at the same time the edge of the first band of absorption creeps on *a little* towards the red, the absorption being usually pretty definite at this edge. The measurements were taken from the points where the light ceased to be sensible, which are represented in the figure by the junction of plain black and shaded white. The shading merely represents the general effect, the gradation of illumination not having been registered. It extends in the figure, as a general rule, too far to the left of the edge of the first black band, and accordingly does not represent the absorption at that limit as sufficiently definite.

A glance at the figure will show how distinctive is the mode of absorption of the rays of high refrangibility by these different substances. Indeed this one character would serve to distinguish all these substances one from another, unless it be morphine from codeine, and caffeine from salicine. The dotted line in the figure for æsculine denotes the commencement of the fluorescence, which is situated near the line G of the solar spectrum. A solution of brucine cuts off the invisible end of the solar spectrum about midway between the lines S and T, and accordingly not far from the end of the region which it requires a quartz prism and lens to see. Accordingly, when these substances are examined by solar light their distinctive characters are almost wholly unperceived, the solutions of some appearing quite transparent, and those of others merely cutting off the extreme rays to a greater or less distance. With æsculine alone the maximum of opacity lies within the solar spectrum; but even in this case we should have little idea of the great increase of transparency about to take place.

The effect of acids and alkalies on all the glucosides referred to in the figure presents one uniform feature. When a previously neutral solution is rendered alkaline, the absorption begins somewhat earlier, when rendered acid somewhat later. With salicine there is merely an indication of this change, falling within the limits of errors of observation; but in the other cases it is quite perceptible, and with phlorizine the shifting of the band of absorption produced by an acid is very large. Fraxine (or paviine) agrees remarkably with æsculine in all its optical characters; the maximum of absorption is merely situated a little nearer to the red, and the tint of the fluorescent light corresponds to a slightly lower mean refrangibility.

Quinine presents no decided maximum of transparency. With this and the other bases observed, with one exception, the absorption, if changed at all, is changed in an opposite manner to the glucosides when the base is set free by ammonia.

Bands of absorption occur also with neutral substances, for example coumarine and paranaphthaline, which last exhibits a system of such bands in the invisible part of the solar spectrum.

Aconitine, atropine, and solanine exhibit no bands of absorption, but merely a general

opacity for the more refrangible rays. The last, indeed, when dissolved in dilute sulphuric acid, is, for this class of bodies, remarkably transparent; while when the base is set free the solution, contrary to what takes place with the other bases, becomes much more opaque, but the absorption is vague. I am not sure, however, how far the purity of the specimen examined may be trusted, though it was white, and regularly crystallized. It would be easy to examine more such substances; but what precedes is sufficient to show the value of the study of the absorption of the rays of high refrangibility, as affording distinctive characters of substances little known.

Minerals.

I have examined a large number of minerals by the rays from the induction spark, both as to their transparency and as to their fluorescence. The transparency of those crystals which were of such a form as to permit it, was examined by holding them in front of a pure spectrum formed on a fluorescent screen. The fluorescence was sought for by forming an image of the spark, for which aluminium electrodes were employed, by the 2·5-inch lens, holding the mineral first at the focus of the visible rays, and then moving it up towards the lens, and watching for any image which might be formed by the rays of higher refrangibility. Should such be observed, its nature was further demonstrated by interposing in the path of the rays a very thin piece of mica. This cut off the image by intercepting the invisible rays, with respect to which, except a small portion of the lowest refrangibility, mica is intensely opaque.

Carbonate of lime, the sulphates of lime, baryta, and strontia, and colourless fluor-spar, were found transparent (sulphate of strontia less so), at least in the qualified sense above mentioned, thus demonstrating the transparency of carbonic, sulphuric, and probably hydrofluoric acid, and of the bases, lime, baryta, strontia. But this subject would be better followed out by salts artificially prepared, and has been investigated by Dr. Miller. In two cases results of considerable interest were obtained with reference to fluorescence.

At the time of writing my first paper, on the change of refrangibility of light, I had found but one mineral, yellow uranite, to the essential constituents of which the property of fluorescence plainly belongs *. In many other cases, both before and since that time, I have observed with solar light fluorescence in minerals, but always apparently having reference to unknown impurities, and therefore to my mind of much inferior interest. By means of the induction spark, employed as above described, I have found one more fluorescent mineral †.

On receiving the image on adularia, and focusing it for the rays of highest refrangi-

* Philosophical Transactions for 1852, p. 524.

† The method by which M. Edmond Becquerel has examined the fluorescence of minerals (Annales de Chimie, sér. iii. tom. lvii. p. 43) does not permit of distinct vision of the specimen from the distance of a few inches, which seems to me necessary to allow the observer to judge whether the fluorescence which may be observed is due to the essential constituents of the crystal or to accidental impurities.

bility, a pair of bluish dots were seen, which were the images of the tips of the electrodes exhibited by fluorescence. As the appearance was everywhere the same, on natural faces and cleavage planes alike, and the same was observed with colourless felspars generally from different localities, it is doubtless a property of the silicate of alumina and potash constituting the crystal. Some specimens, it is true, did not show the effect so strongly as adularia or moonstone; but this is easily explained by the greater purity of the latter varieties. For the fluorescence extended to a very sensible though small depth within the crystal, and yet the rays producing it were cut off by a film of mica much thinner than paper. The intense opacity of mica is doubtless due to peroxide of iron, which nevertheless forms no more than perhaps 5 per cent. of the mineral. Hence a very small percentage of peroxide of iron, or any other impurity having a similar absorbing action, would suffice greatly to reduce the quantity of fluorescent light emitted.

In a concentrated solar beam passed through a suitable absorbing medium, adularia did not show the least sign of fluorescence, in which respect it notably differs from common glass, such as window-glass.

The other case of interest relates to a particular variety of fluor-spar found at Alston Moor in Cumberland. This variety is very pale by transmitted light, being in part of a brownish purple colour, shows a strong blue fluorescence, and is eminently phosphorescent on exposure to the electric spark. On presenting such a crystal to the spark passing between aluminium electrodes, besides the usual blue fluorescence there is seen another of a reddish colour, extending not near so far into the crystal. On receiving on the crystal the image of the spark, and moving the crystal from the focus of the invisible rays towards the lens, it was soon in best focus for the rays producing the blue fluorescence. It had to be moved much nearer to the lens before it came into focus for the rays producing the reddish fluorescence, and was then at the distance at which a well-defined image of the tips of the electrodes is formed on the uranium salt; which proves that the reddish fluorescence was produced by the rays belonging to the bright lines (considered as a whole) of aluminium of extreme refrangibility.

The crystal which showed this effect best was externally colourless for about the $\frac{1}{30}$th of an inch, which stratum showed no fluorescence when examined in this way. Then came one or two strata, parallel to the faces of the cube, showing the ruddy fluorescence, and exhausting apparently the rays capable of producing that effect. The blue fluorescence extended much deeper, and presented a stratified appearance, as Sir David Brewster long ago observed.

On admitting a pencil concentrated by a quartz lens parallel to and almost grazing a face of the cube, so that the rays traversed the colourless stratum, the reddish fluorescence was observed in the stratum which produced it to a long distance from the face by which the rays were admitted, which demonstrates the transparency of fluoride of calcium for the rays of very high refrangibility.

The property of exhibiting such a well-marked effect under the exclusive influence of rays of extreme refrangibility, renders such a crystal a useful instrument of research.

Several other metals besides aluminium show the reddish fluorescence; but none of those examined showed it so well, partly because it is evidently produced more copiously by aluminium electrodes, and partly because it is less masked by the blue fluorescence, the spectrum of aluminium being rather wanting in brightness until the region of extreme refrangibility is reached.

If the crystal be held near the electrodes, and observed while their distance changes, it will be found that on passing from the greatest striking distance the reddish fluorescence decidedly improves. On still further diminishing the distance between the electrodes, the reddish fluorescence appears still to increase; though whether this is a real absolute increase or only an increasing preponderance over the blue, it is not easy in this way to say for certain. Hence the copiousness of rays of high refrangibility increases at first, and continues to increase *relatively* if not absolutely. It is supposed that the jar is sufficiently large to prevent the discharge from degenerating into what will be presently described as the arc discharge.

If the crystal be held close to the contact-breaker when the secondary terminals are separated, and the effect be compared with that of the secondary discharge (a jar being in connexion, as has been supposed all along), the electrodes being of platinum for fairness of comparison, it will be found that the proportion of rays of extremely high refrangibility is decidedly greater for the spark at the contact-breaker than for the secondary discharge.

On forming by the 2·5-inch lens an image of the spark from aluminium electrodes, and placing a crystal, such as that above mentioned, in the focus of the rays producing the reddish fluorescence, it is easy to determine the transparency or opacity of substances for those rays, the alteration of the focus by the introduction of a thick plate being of course borne in mind, and the crystal moved accordingly. The rays forming the image have had to pass only through air, and through a very small thickness of quartz, before reaching the crystal. In this way I have found that even quartz itself in very moderate thickness is opaque for these rays; but different specimens, or different parts of the same specimen, vary in this respect. I possess a large plate 0·42 inch thick, cut perpendicular to the axis of the crystal, which is generally transparent, but is slightly brownish on one side, to the distance of about half an inch from the face of the hexagonal prism. The *colourless* part of this plate, beyond a little distance from the brownish part, is opaque for the rays in question *, while the *brownish* part is nearly transparent. It may be inferred that the colourless part contains a minute quantity of some impurity capable of absorbing these rays, which does not exist, at least to the same extent, in the brownish part, although the latter is not perfectly pure silica, as is shown by its colour. On the

* It should be mentioned that this part contains those delicate, definitely directed, elongated laminæ or crystals, hardly visible except in a beam of sunlight, which are called by practical opticians "blue shoots." An examination of a number of cut pieces of quartz lent me by Mr. Darker confirms me in the suspicion that such crystals are more defective in transparency than other colourless specimens for the rays of extreme refrangibility.—July 1862.

whole, I am disposed to think that quartz, if it were *rigorously* pure, would be transparent. We see at any rate how difficult it is to draw certain conclusions respecting the transparency or opacity of a substance which, in the state of purity in which it may be obtained, shows only a slight defect of transparency.

I tried reflecting the rays from the spark by a fine Munich grating, but the light was far too faint to be of any use. Possibly a large and very closely ruled plane speculum, with a concave speculum instead of a lens, might give light which it would be possible to observe. But at present I have not found any sufficiently marked effects referable to rays of still higher refrangibility to make it worth trying.

The same crystal which showed the reddish fluorescence was eminently phosphorescent, with a blue colour. The phosphorescence, like the fluorescence, was arranged in strata parallel to the faces of the cube, and, like the reddish but unlike the blue fluorescence, was not perceptible beyond a moderate distance from the surface at which the exciting rays had entered. On forming an image of the discharge by the 2·5-inch lens, focusing the crystal for the rays producing the reddish fluorescence, fixing it there, and breaking the circuit after the induction coil had worked for a little while, a dart of blue phosphorescent light was seen in the crystal at the focus of the lens. On focusing for the rays most efficient in producing the blue fluorescence, the reddish was diffused over a broad portion of the strata producing it; and on repeating the above experiment in this position of the crystal, the blue phosphorescence was seen similarly diffused. This shows that the rays of extremely high refrangibility are those most efficient in producing the blue phosphorescence.

[We may suppose that the blue fluorescence, the reddish fluorescence, and the blue phosphorescence are due to the action of the assemblage of heterogeneous exciting rays on the same substance (doubtless some impurity taken up during crystallization), or on two or three distinct substances. The blue fluorescence is produced abundantly at a depth within the crystal at which the two other effects are invisible; but this alone is no proof of a diversity in the nature of the substance acted on, because the rays producing the two latter effects would have been absorbed before arriving at such a depth. Hence it is among the early strata, in crossing which rays capable of producing each of the three effects are still vigorous, that evidence must be sought, in the coincidence or non-coincidence of the strata in which the three effects are respectively perceived, of the probable identity or certain diversity of nature of the substance acted on. At the time when this paper was read I fancied I had observed slight discrepancies as to coincidence in the strata. But a renewed examination, in which a larger number of specimens were observed, leads me to regard the fancied discrepancies as too doubtful to rely upon and to overpower the increasing weight of evidence on the other side.

The blue fluorescence may be observed in the early strata (which ordinarily, at least with electrodes of aluminium and several other metals, show a red) by absorbing the more refrangible of the exciting rays by a suitable plate of quartz, or else by substituting for aluminium some metal, such as magnesium, which is poor in rays of extreme refran-

gibility. On the other hand, the red fluorescence really existing in the early strata, when it is overpowered by the blue, may be seen by viewing the crystal through a solution of chromate of potash, which greatly enfeebles the blue fluorescence, while at the same time it transmits enough of the spectrum to allow the unabsorbed residue to be at once distinguishable by its colour (green) from the red fluorescence. In this way the red fluorescence may be readily perceived even with electrodes of magnesium. Again, a particular stratum which showed a blue fluorescence when acted on by rays which entered by a face of the cube, and before reaching it had to traverse some other strata showing fluorescence, exhibited a red fluorescence when acted on by rays which fell on it directly, having been admitted through an octahedral face.

It is more difficult to decide as to the identity or diversity of the strata showing respectively red fluorescence and blue phosphorescence, because the two effects are observed in a different way; but as far as I could decide, the strata appeared to correspond.

On the whole, then, I am disposed to think it probable that it is the same substance which, in consequence of the action of rays beginning with a part of the violet and extending from thence onwards, exhibits a blue fluorescence, which, in consequence of the action of rays of extreme refrangibility, exhibits a red fluorescence, and which, in consequence of the action of rays of a similar refrangibility, exhibits a powerful blue phosphorescence. At least, if the substances be different they would appear to have coexisted in solution, and so to have been taken up together in the crystallization of the mineral. I should mention, however, that it is contrary to all my experience that the fluorescence of a single substance (*i. e.* not a mixture) should thus, as it were, take a fresh start *with a totally different colour* on proceeding onwards in the spectrum; but then my experience is derived mainly from the examination of substances in the comparatively short solar spectrum.—July 1862.]

I have said that the phosphorescence was produced in certain strata within the crystal. These strata were in some places sharply terminated, so as to be foreshortened into well-defined lines. On watching the phosphorescence, there was nothing to be seen at all like conduction; the strata remained sharply defined as long as the light was strong enough to enable one to judge. This is at variance with one of the two results which, on the authority of others, I formerly mentioned as indicating a distinction between phosphorescence and fluorescence *. On trying shortly afterwards along with Mr. Faraday, I could not obtain either of these results. One of them, that relating to apparent conduction, which was obtained by MM. Biot and A. C. Becquerel, has since been explained by M. Edmond Becquerel as an illusion of observation †. The other, that relating to the production of phosphorescence in Canton's phosphorus by rays which had traversed a strong solution of bichromate of potash, I am, after a conversation with Dr. Draper, still unable to explain.

* Philosophical Transactions for 1852, p. 547. † Annales de Chimie, tom. lv. (1859) p. 112.

Advantage of Broad Electrodes.

At first I employed by preference wires or sharp pieces of metal for electrodes, in consequence of the greater facility with which the discharge passed, and the larger quantity of light given out by the spark. Certain considerations, however, led me to try broad electrodes; and I accordingly procured electrodes of the common metals shaped like small watch-glasses, about an inch in diameter. These showed in some cases a most marked superiority over thin wires, exhibiting the invisible metallic lines in far greater strength, while with some metals there was not much difference. With copper, for example, the superiority was very great, with iron it was comparatively small.

Instead of electrodes of this shape, it is sufficient to take two pieces of thick foil, make them slightly cylindrical by means of a round ruler, or a pencil, and mount them with their convexities opposed and the axes of the cylinders crossed.

Besides copper, silver, tin, and aluminium show a great advantage of flat electrodes, and lead a moderate advantage, while with zinc, as with iron, sharp electrodes are nearly as good. Brass agrees in this respect with zinc, and not with copper, though it shows the copper lines very strongly.

With such electrodes, however, the spark dances about; and its unsteadiness is objectionable in some experiments. A good part of the advantage of flat electrodes is however retained if one only be flat, especially if this be negative, and the spark is now steadier. Instead of using the end of a wire to combine with a flat electrode, it seems rather better, according to a plan suggested to me by Dr. MILLER, to bend a wire to a gentle curve lying in a vertical plane passing through the prism; or the edge of a flat piece of metal may be similarly employed.

On forming an image of the spark between a sharp and a flat electrode of copper, and receiving it on a fluorescent screen, the flat electrode gave the brighter of the two images already mentioned, and that, whether the electrode were positive or negative.

On similarly forming an image of the spark between two very broad elocktrodes, and focusing for the rays of highest refrangibility, the image did not, as usual, consist of two separate dots; but whether it was, that, from the shortness of the spark, the two ran into one, or that the rays belonging to the metallic lines of high refrangibility were emitted throughout the whole length of the spark, I am not quite certain; but I incline to the latter opinion, as a separation of the discharge into two portions, corresponding to the immediate neighbourhood of the two electrodes respectively, could hardly have escaped detection had it existed.

Arc Discharge, and Lines of Blue Negative Light.

On diminishing the distance between the electrodes, formed suppose of copper wires, the brightness of the metallic lines at first improves, and afterwards changes but little, or, if anything, rather falls off. On still further diminishing the distance, so that the electrodes almost touch, and the discharge passes with little noise, a new set of strong lines make their appearance in the invisible region of moderate refrangibility. In this

mode of discharge, in which the negative electrode, if at all thin, quickly becomes red-hot and fuses, the jar has not much influence, and the lines in question are still better seen when it is suppressed altogether. To show them to perfection, it is best to take a flat negative electrode, so as to carry off the heat, and not to hide from the prism any part of the blue negative light, and a sharp positive electrode almost touching the former. In this way the visible discharge is reduced almost wholly to an insignificant-looking star of blue light; but it is wonderful how strong an effect it is capable of producing in the invisible region. The most striking part of the invisible spectrum consists of four bright lines, numbered 1, 2, 3, 4 in fig. 1, situated not far from the visible spectrum. These are followed, after a nearly dark interval, by light arranged in masses resembling in its general aspect the groups of copper lines (from which, however, it differs), but not strong enough to be resolved or accurately measured. The figure represents also a couple of blue bands (b, b') seen by projection. These are not seen on looking at the blue light directly with a flint-glass prism of 60°, because everything is seen in too great detail. Most of the air-lines in the invisible spectrum, especially the bands beyond line 4, have an ill-defined look, and would probably be resolved did the intensity of the light permit.

The appearance just described is independent of the nature of the electrodes, and therefore is to be referred to the air, and not to the metal. On viewing in a moving mirror the star of light producing this effect, it is found to have a considerable duration.

On slightly separating the electrodes, forming an image of the discharge with the 2·5-inch lens, and receiving it on a cake of the uranium salt, a very strong fluorescence was seen over the image of the blue disk when the lens was focused for a point a little beyond the visible spectrum. On moving the lens onwards, the fluorescence produced by the rays belonging to this image spread out into a ring; and on moving still further, a tolerably well-defined image of the whole discharge was perceived. Of this the part belonging to the blue disk was the brightest, and was surrounded concentrically by the ring before mentioned, now still further widened. The image of the remainder of the discharge was brightest where it was most contracted at the positive electrode. The discharge generally was perhaps of slightly higher refrangibility than the blue disk, even excluding from the latter the rays belonging to the ring. It thus appears that the four bright lines figured were produced mainly by the blue negative light.

The mode of transition of the discharge may be studied by placing the electrodes at the greatest striking-distance and making them gradually approach. At first there passes a clean bright spark making a sharp report, and not resolved by a revolving mirror. The invisible spectrum which this shows is too faint for precise observation; the visible spectrum shows chiefly air-lines. As the electrodes approach, the spark becomes clothed by the well-known yellowish envelope capable of being blown aside, and the blue negative light begins to appear. A moving mirror, as M. Lissajous has already observed*, shows an instantaneous spark at the commencement, in point of time,

* See Du Moncel, 'Recherches sur la non-homogénéité de l'étincelle d'induction,' p. 107.

of the envelope and blue negative light, both which are drawn out, indicating a very appreciable duration. On making the electrodes approach somewhat nearer, the spark diminishes, and the envelope is formed in perfection, especially with broad electrodes. The air-lines now begin to show themselves well, but are brightest on the side of the spectrum answering to the blue negative light.

It might be supposed at first sight that the permanence of the yellowish and of the blue light only indicated a glow of appreciable duration left by a sensibly instantaneous discharge; but several circumstances indicate that the discharge itself lasts, and that it is *under* its action that the glow takes place*. The action, I am persuaded, is this: a spark first passes; and this enables a continuous discharge to pass, which is due, in part at least, to the inductive action of the still falling magnetism, just as a voltaic arc may be started in a powerful battery by passing an electric spark between the slightly separated electrodes; and the glowing of the air *under the action* of this discharge produces the yellowish envelope and blue negative light. Thus, when the electrodes are nearly at the greatest distance at which this sort of discharge takes place, the blue negative light is seen pretty sharply terminated in a moving mirror. Were it a dying glow, it ought to fade away; but if produced under a discharge, it ought to cease almost abruptly, inasmuch as at this distance of the electrodes a continuous discharge is unable to pass when the tension has sunk much below that under which it was first produced.

The same conclusion may be drawn from an effect which I once obtained, the exact conditions for the production of which it is not easy to hit off. With a jar in connexion, each discharge due to a single breach of contact appeared in a moving mirror as a bright spark joined to a spark less bright by the blue negative light, and also by the yellowish or reddish light, brightest close to the positive electrode. Were the blue light due to a glow, it ought to be reinforced instead of being put out by the second spark, whereas the explanation of the result is easy on the supposition of a continuous discharge. The first spark started a continuous discharge, which emptied the jar less fast than it was filled by the secondary coil; so that presently another discharge took place, which emptied the jar so that a continuous discharge could no longer pass.

On viewing the broad discharge formed without a jar when the electrodes are at a moderate distance, through a revolving disk of black paper with a single hole near the circumference, while the envelope was being blown aside, so as to get a succession of momentary views of the discharge, the envelope was seen *extravagantly bent*, as a flexible conductor might have been—not *torn across*, as a column might have been which was heated by a *previous* spark. The central spark, of course, was usually missing, as it is sensibly instantaneous.

I have spoken of the arc, and especially the blue negative light, as exhibiting air-lines. The arc, however, is liable to be coloured not only by casual dust (as when it passes partly through the flame of a spirit-lamp with a salted wick, when it is coloured yellow

* Although this view may be considered already established (see the work by the Vicomte Du Moncel just quoted), the observations here mentioned will not, I hope, be altogether useless.

by sodium), but also by matter torn from the positive electrode. This is well seen with electrodes of aluminium, when the arc or a portion of it is frequently coloured green. This green light has a very sensible duration, and a distinctive prismatic composition, and is brighter towards the positive than towards the negative electrode, but is not confined to the immediate neighbourhood of that electrode (extending indeed sometimes over almost the whole length of the arc), in which respect, and in its duration, it differs from the light of the spark proper*. With aluminium opposed to another metal, as copper or iron, the green light is seen only when the aluminium is positive. Even with aluminium this light may generally be got rid of by making the electrodes approach; and it is the arc in what may thus be deemed its normal state that was observed for the construction of the last line of fig. 1, though I have not at present noticed variations in the invisible corresponding with those in the visible spectrum of the arc discharge.

On the Cause of the Advantage of Broad Electrodes; and on the Heating of the Negative Electrode.

Although the spark appears instantaneous when viewed in a moving mirror, it must yet occupy a certain time; so that we have in fact a brief electric current, to which we may apply OHM's laws. The electromotive force is here the difference of tensions of the coatings of the jar. As to the resistance, the short metallic part of the circuit may be neglected, and we need only attend to the place of the discharge. The resistance here may be divided into that due to the air and that due to the parts of the electrodes close to the points of discharge. That the latter is by no means insignificant, may be inferred from the enormous temperature to which minute portions of the electrodes are raised, as indicated by the excessively high refrangibility of the rays emitted by the metals, in the state doubtless of vapour. By the use of flat electrodes the striking-distance is materially diminished, without any change in the difference of tension of the coatings of the jar. Hence the electricity which it contains passes at a higher velocity, and therefore produces a more powerful effect on the metals.

The injurious effect of the introduction of a small resistance was very strikingly shown with broad, slightly curved copper electrodes, three inches in diameter, by leading wires from a coating of the jar into a tumbler of water, and from thence to the corresponding electrode, when the spark became quite insignificant in comparison to what it had been.

With one sharp and one flat electrode placed near together, bright sparks passed when the connexion was metallic, and the invisible spectrum then showed the copper lines, with one or two air-lines not conspicuous; but when water was interposed the spark was greatly reduced, and the invisible spectrum showed the air-lines. In both cases the spark was followed by an arc discharge, as might be seen in a moving mirror; and in the latter case the arc discharge was increased in consequence of the diminution

* The *outer* part of the jar-spark between aluminium electrodes has the same green colour and prismatic composition, though in this case the green light is sensibly instantaneous.—July 1862.

of the spark, which, though necessary to start it, was formed at its expense; and as in the arc discharge the jar was idle, the increase of resistance in a circuit already comprising the secondary coil was unimportant.

The fact that the blue negative light which appears when the arc discharge is formed shows air-lines, points to the air as the seat of the intense action which there takes place; and the very high refrangibility of some of the rays emitted, and the copiousness of those rays, indicate how intense that action is. The heating of the negative electrode seems to be a secondary effect, not due to the direct passage of the electricity through the metal (for the section through which it passes is not by any means small), but to the heat communicated from the film of air investing it. Small as is the mass of the film compared with that of the portion of the electrode adjacent to it, the rate at which heat is communicated is enormous. Thus with a positive point nearly touching underneath a negative electrode of platinum foil containing water, the foil is kept red-hot under the water, though the mere passage of electricity through the metal would be quite inadequate to produce that effect. Corresponding to the heating of the electrode by the air is the cooling of the air by the electrode; and such a powerful abstraction of heat can hardly take place without altering the state of the film of air in relation to its power of conducting electricity. This would seem to be the reason why the film of air in contact with the negative electrode behaves so differently from any arbitrary section of the column along which the discharge takes place, and from offering greater resistance becomes the seat of a more intense emission of highly refrangible rays. At the positive electrode, at which, for whatever reason, the issue of electricity is confined almost to a point, nothing of this kind takes place; but, from the contraction of the section through which the electricity has to pass in the electrode, a minute portion of the metal of which it is composed is so highly acted on that matter belonging to the electrode is liable to appear in the arc.

These views lead to curious speculations respecting the negative light in highly exhausted tubes, and respecting the remarkable reversion of heating-effect which Mr. Gassiot has obtained according as the discharge is intermittent or continuous*, but I forbear to speculate further.

* Proceedings of the Royal Society, vol. xi. p. 329.

XXVIII. *On the Nature of the Forces concerned in producing the greater Magnetic Disturbances.* By Balfour Stewart, *M.A., F.R.S.*

Received June 14,—Read June 19, 1862.

1. In a previous communication submitted to the Royal Society on June 28th, 1861, and since published in their Transactions, I ventured to make a suggestion regarding the nature of that connexion which subsists between magnetic disturbances, earth-currents, and auroras.

In this hypothesis the earth was viewed as similar to the soft iron core of a Ruhmkorff's machine, in which a primary disturbing current was supposed to induce magnetism. Earth-currents and auroras, on the other hand, were viewed as induced or secondary currents, caused by the small but abrupt changes which are constantly taking place in the strength of the primary disturbing current, these changes being very much heightened in effect by the action of the iron core, that is to say, of the earth.

2. These small and rapid changes are very observable in the photographic traces given by the Kew magnetographs during a time of disturbance. At such a time the curves for all the three elements invariably present a serrated appearance, which, when the disturbing cause is very powerful, is magnified into a succession of sharp peaks and hollows, and these exhibit a frequency of change which makes them comparable in this respect with earth-currents and auroras.

These peaks and hollows are therefore regarded by this hypothesis as denoting the changes which take place in the action of the primary disturbing current upon the needle through the intervention of the earth's magnetism, or, since the existence of a primary current is really unnecessary as an explanation, we may dispense with it altogether *, and regard these photographic peaks and hollows as simply representing the changes which take place in the magnetism of the earth, without speculating upon the cause of such changes.

3. In the paper already alluded to, in discussing the great magnetic storm extending from August 28 to September 7, 1859, I endeavoured to show that the first effect of the superimposed disturbing force was to diminish both elements of the earth's magnetism during a period of about six hours. This grand wave, constituting the great body of force, could not, I remarked, be supposed to be due to any combination of earth-currents of which the period is only a few minutes. Under these circumstances it would seem to be the most natural supposition to regard the peaks and hollows, which occur as it were on the surface of the great disturbance wave, as representing rapid changes in the in-

* This was suggested to me by Professor Tyndall.

tensity of the disturbing force, and therefore not as phenomena caused by earth-currents, since the great body of the disturbance of which they represent the changes cannot be due to any such cause. Auroras and earth-currents being thus removed out of the list of causes, might then be supposed to follow rather as effects of these magnetic changes, on the principle of voltaic induction already mentioned. As, however, there seems to be a tendency to regard the motions of the magnetic needle as due to the direct action of earth-currents, it may be desirable here to inquire whether this view of the origin of these small and rapid disturbances is capable of being accepted as a tenable hypothesis.

4. It is almost unnecessary to remark that the hypothesis which asserts that earth-currents are not the cause of the small and rapid magnetic disturbances, does not assert that such currents have absolutely no influence upon the needle, since we know that a current must always act upon a needle; but it maintains that these currents are induced and secondary phenomena, and therefore represent only a small fraction of the whole force in operation, and react on the magnet only to a very limited extent.

5. The interesting observations on earth-currents made under the direction of Mr. C. V. Walker, and recorded by him in a paper recently published in the Transactions of the Royal Society, appear to furnish grounds for an hypothesis regarding these phenomena.

By reference to a map appended to his paper, it appears that a line drawn from the Ramsgate to the Margate telegraph station proceeds in a direction 12° 50′ W. of true north; or, assuming 21° 30′ W. as the approximate magnetic declination, this line proceeds in a direction 8° 40′ E. of magnetic north. In like manner, a line drawn from the Ashford to the Ramsgate telegraph station proceeds in a direction 83° 50′ E. of magnetic north; also a line drawn from the Ashford to the Margate station in a direction 77° 42′ E. of magnetic north.

By Mr. Walker's observations from August 29 to September 2, 1859, and also from August 8 to August 10, 1860, it would appear that a current proceeding from Margate to Ramsgate was always simultaneous with one proceeding from Ramsgate to Ashford, and with one proceeding from Margate to Ashford; that is to say, simultaneous currents proceeding along these lines were either all north or all south currents.

Let us endeavour to ascertain how far this agrees with the behaviour of the magnetographs at Kew during these two disturbances on the hypothesis of direct action, assuming also with Mr. Walker that earth-currents are derived from a stream of electricity which is drifting across the country.

Conceive now a current resolved into two components, the one proceeding in the magnetic meridian, and the other in a direction perpendicular to it; and let us agree to consider as positive those currents flowing from magnetic north to south, and from magnetic east to west. Of these two components, the first only will affect the freely suspended declination magnet, a positive current tending to increase the westerly declination; while the latter only will affect the horizontal-force magnet which has been twisted into a position at right angles to the magnetic meridian, a positive current increasing the horizontal force.

Let x be the value of the north and south, and y that of the east and west component of a current as deduced from its effects upon the magnetographs.

This will give on the Margate and Ramsgate line a current represented by

$$A\{x \cos 8^\circ 40' + y \sin 8^\circ 40'\}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1.)$$

while for the Ramsgate and Ashford line we shall have

$$B\{x \cos 83^\circ 50' + y \sin 83^\circ 50'\}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2.)$$

and for the Margate and Ashford line

$$C\{x \cos 77^\circ 42' + y \sin 77^\circ 42'\}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3.)$$

where A, B, C are positive constants depending upon the nature of the soil and strata along the various lines.

Now in the disturbance of 8th to 10th August 1860, the declination and horizontal force were increased simultaneously, or they were diminished simultaneously; hence x and y have the same sign, and the expressions within brackets are either all positive or all negative, that is to say, the currents between these lines should have been either all north or all south simultaneously. This was observed to be the case. In this instance, therefore, there is nothing to contradict the hypothesis which makes earth-currents the cause of magnetic disturbances.

Let us now examine the disturbance of August 29 to September 2, 1859. Here the horizontal force was increased when the declination was diminished, and *vice versâ*; and if we represent by unity the current influential in disturbing the former element, that disturbing the latter is most probably represented by $-\cdot 46$ (see Table V.).

Hence (1.), (2.), (3.) become

$$(1) = A\{-\cdot 46 \cos 8^\circ 40' + \sin 8^\circ 40'\} = -\cdot 304\, A,$$
$$(2) = B\{-\cdot 46 \cos 83^\circ 50' + \sin 83^\circ 50'\} = +\cdot 945\, B,$$
$$(3) = C\{-\cdot 46 \cos 77^\circ 42' + \sin 77^\circ 42'\} = +\cdot 879\, C,$$

We thus see that in this disturbance, for the theory to hold good, currents of one name should have traversed the line between Margate and Ramsgate, while currents of the opposite name traversed the other two lines; but this is not in accordance with the observations made, which showed that currents of the same name traversed the three lines simultaneously. In one word, the proof against the theory of the direct action of earth-currents in causing disturbances may be summed up by saying that, while the magnetic disturbances of September 1859 and August 1860 were of opposite character, the corresponding earth-currents, as determined by these three telegraphic lines, were of the same character.

6. At first view it would almost appear as if this fact, which seems conclusive against earth-currents (at least those earth-currents observed in this country) being the direct and main cause of disturbances, were equally conclusive against their being induced currents, since the effect of such upon the telegraph needle might be supposed opposite in character to that which would be produced by such currents as would directly cause magnetic disturbances, the two effects being antithetically and therefore definitely related to each other.

But this difficulty will disappear when we reflect that earth-currents may be twisted in passing over the surface of our globe. Although, therefore, we may not find that oppositeness of character which we naturally associate with induced currents, yet the study of particular earth-currents in connexion with simultaneous magnetic disturbances may perhaps serve to throw some light upon the nature of the former.

7. The following is brought forward as an instance of this. On September 1st, 11.20 A.M. G. M. T., a *strong southerly* current was noticed on the Ashford and Margate line which lasted till 11.26 A.M., while from 11.28 A.M. to 11.35 A.M. a *slight northerly* current was observed on the same line.

If we take into account a slight delay in the starting of the Kew curves (equal to about 2 minutes) due to the slackness of the toothed wheels which drive the cylinders, we find the first recorded appearance of the south current to be, in point of time, $1\frac{1}{2}$ minute behind that of a very abrupt disturbance which affected all the magnetic elements at Kew, and which occurred simultaneously with the outbreak of a curious phenomenon on the sun's disk. Whatever be the cause of this apparent difference in time, I do not think that it argues any want of simultaneity between the magnetic disturbance and the earth-current, and we may safely suppose that the first outbreak of the south current was really simultaneous with the commencement of the disturbance at Kew.

The magnets at Kew were affected in the following manner. The westerly declination was at first rapidly increased; but soon the disturbing force attained its maximum, and then gradually diminished, until ultimately the needle attained nearly the same position which it had before the disturbance. The horizontal force was at first rapidly diminished, then as the disturbing force died away it also gradually came back to its previous value. A direct current which would cause a disturbance of this nature would be one at first rapidly increasing, then gradually diminishing, but always preserving the same name, whereas the induced effect of such a disturbance would be at first a strong current in one direction, and afterwards a weak current in the opposite direction. The latter character agrees very well with that of the currents between Ashford and Margate, the former character not in the least. Judging therefore from this disturbance, and, though only a single example, it appears to be an unexceptionable one, it would seem that earth-currents do not cause magnetic disturbances, but are rather the induced currents which the latter give rise to.

8. I shall now endeavour to show that we have grounds for supposing the magnetograph peaks and hollows to be due to changes in the value of the disturbing force.

The action of any such disturbing force is of a twofold nature.

1°. It raises a curve above its normal position, or depresses it below the same, visibly and for a somewhat lengthened period of time.

2°. The curve which represents this definite action of the force is at the same time studded with sharp peaks and hollows.

Now if the second of these two effects denotes the changes which occur in the force

producing the first, the peaks and hollows should be similar in character to the general effects of the force. The following example will explain what is meant.

If we have a force which simultaneously and for a lengthened period of time raises up the curves of all the three elements nearer to the top of the paper, and if the peaks and hollows denote changes taking place in the intensity of this force, then all the three elements should exhibit peaks at once, or hollows at once. But if, on the other hand, the general appearance of the curves represents the declination as raised up while both the other elements are depressed, then a peak in the former should correspond to a hollow in the latter two.

9. I requested Mr. CHAMBERS, Magnetical Assistant at Kew, to note his impression of the general appearance of the disturbance curves of most importance for the years 1858, 1859, and 1860; and the following Table is the result. The sign + means that the curve is raised towards the top of the paper, the sign − means that it is lowered towards the bottom.

TABLE I.—General appearance of Disturbance Curves.

Date.	Character of disturbance.		
	Declination.	Horizontal force.	Vertical force.
1858. March 28—29	−	+	+
April 9—10	−	−	−
June 23—24	+	−	−
July 5—6	0	−	−
October 27—28	indefinite.	indefinite.	+
December 4—5	+	+	−
1859. February 9—10	+	0	−
February 9—10	+	0	+
February 26—27	−	indefinite.	−
April 21—22	−	−	−
April 21—22	+	+	+
April 29—30	−	−	−
May 19—20	−	−	−
June 8—9	−	−	−
June 8—9	indefinite.	+	+
July 11—12	0	−	−
July 18—19	−	0	−
August 28—29	−	+	+
September 1—2	−	+	+
September 2—3	−	−	−
September 3—4	−	−	−
October 12—13	−	−	indefinite.
October 17—18	+	+	+
October 17—18	−	+	+
October 18—19	−	−	−
October 18—19	−	+	+
December 13—14	−	−	−
December 13—14	indefinite.	0	−
December 14—15	−	0	+
1860. March 28—29	−	−	+
March 29—30	−	−	−
April 9—10	−	−	−
April 9—10	+	+	+
July 4—5	+	+	+
July 5—6	−	−	−
August 6—7	indefinite.	−	0
August 7—8	0	−	−
August 8—9	−	−	−
August 9—10	0	−	−
August 12—13	−	−	−
August 12—13	−	+	+
September 7—8	−	−	−

It thus appears that there are twenty-two cases in which the declination is raised or lowered along with the horizontal force, and only seven cases of an opposite description. Also there are twenty-two cases in which the declination is raised or lowered along with the vertical force, and only eleven cases of an opposite description. Finally, there are thirty-one cases in which both forces are raised or lowered together, and only two cases of an opposite description.

There is therefore a decided tendency in the curves of all the elements to be raised or lowered simultaneously; but this tendency is stronger between the horizontal and vertical-force curves than between either of these and the declination. It may at the same time be affirmed that, with the exception of the disturbance of August—September 1859, there is no very prominent case in which the three elements do not rise or fall together.

10. Having thus recorded the general appearance of the curves, I shall now give the result of the examination of the simultaneous peaks and hollows; but it will first be necessary to state the method in which this has been conducted.

Each curve has a zero-line, or line of abscissæ, along which the times are reckoned; so that if we wish to find the time corresponding to any point in the curve, we have merely to measure its abscissa, the commencement of the zero-line (denoting the moment at which the instrument was started) being the origin.

In like manner, it is equally easy to find the point of the curve corresponding to any given time.

The accuracy of this process depends, however, it will be seen, on the assumption that the time-scale is constant for the different portions of a curve; and the following is a proof that this is strictly true.

It will be noticed shortly that this system of measurement has brought out a remarkable correspondence between the peaks and hollows of the horizontal force and those of the vertical force, which may be said to have failed in no one instance. This may be received as sufficient evidence, not only of the physical fact brought to light, but also of the constancy of the time-scale, in absence of which no such phenomenon could have been observed.

11. The following Table exhibits the results derived from comparing together the peaks and hollows of the declination, with those occurring at the same instant of time in the horizontal force.

When peak and peak occur together, or hollow and hollow, this is termed a correspondence, the reverse a non-correspondence.

TABLE II.—Exhibiting the connexion between the small movements of the declination and those of the horizontal force in the various disturbances.

Date of disturbance.	Number of correspondences.	Number of non-correspondences.	Doubtful.
1858. March 12—16	18	1	5
April 9—12	24	0	5
June 22—24	13	0	1
October 27—29	15	0	0
December 4—6	12	1	1
1859. February 8—10	13	2	1
February 26—28	19	0	2
April 21—23	14	0	1
April 29—May 1	15	0	1
May 19—21	14	0	0
June 8—10	13	0	1
July 11—13	10	0	5
October 12—14	8	1	2
October 17—19	19	0	2
December 13—15	9	0	1
1860. March 26—30	29	0	2
April 9—11	22	0	5
April 13—15	15	1	1
June 29—July 6	28	0	3
August 6—13	65	12	46
September 7—8	7	0	0
Sums...	382	18	85

It will be seen from this Table that, in the great majority of cases, a peak in the declination corresponds to a peak in the horizontal force, and a hollow in the one to a hollow in the other. It is proper to mention that the peaks and hollows here observed are those which represent sudden changes of short duration; for if we take for comparison some prominent peak or hollow in the one curve having a long period, we shall be much less certain of finding a corresponding phenomenon in the other.

12. When the peaks and hollows of the horizontal force and those of the vertical force are compared together, the result is that a peak invariably corresponds to a peak, and a hollow to a hollow; and even when large prominences of long duration are taken, the correspondence between the two curves is very remarkable.

The same connexion, therefore, which subsists between the sudden movements of the declination and those of the horizontal force, holds still more strikingly between those of the two forces.

13. The disturbance of August—September 1859 has been purposely left out of Table II.; in the following Table this great disturbance has been broken up into parts, for each of which the behaviour of the peaks and hollows is compared with the general appearance of the curve.

TABLE III.—Great disturbance extending from August 28 to September 7, 1859. The behaviour of peaks and hollows compared with the general appearance of the curves.

Time.	Declination movements compared with those of the horizontal force.			General character of the disturbance.
	Correspondence.	Non-correspondence.	Doubtful.	
1859. August 28, 10 A.M. to 9 P.M.	10	0	1	The great disturbance had not yet commenced.
August 28, 10.30 P.M. to August 29, 9.52 A.M.	0	6	0	The great disturbance had now commenced depressing the declination and raising both elements of the force.
September 2, 4.50 A.M. to September 3, 11.50 A.M.	0	20	2	A second great disturbance commenced about September 2, 4.50 A.M., depressing the declination and raising both elements of the force, which changed into or was succeeded by one which seemed to impress all the elements in the same manner.
September 3, 1.40 P.M. to September 4, 10.30 A.M.	9	13	3	
September 4, 12.30 P.M. to September 6, 9.30 A.M.	16	3	7	

14. Before discussing the results in this Table, I ought to mention that in this great disturbance the rapid nature of the motion makes the comparison of simultaneous peaks and hollows a matter of some little uncertainty. On the other hand, these comparisons have been much facilitated by the exceedingly good definition which the labours of the late Mr. WELSH secured for the Kew curves, without which, indeed, an investigation of this nature would have been impossible. On the whole, I am well persuaded that the results in Table III. represent the truth.

15. To recapitulate. It appears from Table I. that, studying merely the general result of a disturbance, there is a decided tendency to raise or lower the curves of all the elements simultaneously, this being stronger between the horizontal and the vertical-force curves than between either of these and the declination.

From Table II. it appears that, if we leave out of account the great disturbance of August—September 1859, a peak of declination corresponds to a peak of horizontal force, and a hollow of the one to a hollow of the other, while the same correspondence holds still more strongly between the horizontal and vertical forces.

Again, from Table III. it appears that the great disturbance of August—September 1859 may be broken up into two. In one of these the general result was to lower the declination and raise both elements of the force, while in the second the result was to raise or lower all the three curves simultaneously. It also appears that, while the first of these disturbances prevailed, a declination hollow corresponded to a peak of either force, and that, on the other hand, while the second prevailed, a declination hollow corresponded to a hollow of either force.

This very marked correspondence between the behaviour of the peaks and hollows and that of the general disturbing force *in all cases*, leaves, I think, little doubt that the former represent sharp and sudden changes in the intensity of the latter.

16. Let us now endeavour to ascertain if any use may be made of this fact to throw light on the nature of the forces concerned in producing disturbances.

17. Two distinct suppositions may be made regarding the nature and mode of action of disturbing forces.

1°. We may suppose that forces of every imaginable variety of character are concerned together in producing disturbances.

2°. We may suppose a disturbance occasioned by one or more groups of forces the elements of which are bound together by a certain law.

With respect to the first of these hypotheses, it is refuted by the discussion of disturbing forces given by General SABINE for the different Colonial Observatories and for Kew, as well as by the results in Tables I., II., and III. The second hypothesis must, therefore, represent the mode of action of the forces concerned.

18. And, first of all, it may safely be affirmed that no disturbance of any magnitude is due to the action of a single force, merely varying in amount; for if this were the case, the distance at any moment of a point in the curve of one of the elements from its normal position should bear throughout a disturbance an invariable proportion to the distance of a corresponding point in the curve of another of the elements from its normal; but this is by no means true.

Since, therefore, a disturbance is not a phenomenon due to the action of a single force, and since at the same time it does not represent the action of a number of different forces promiscuously huddled together, it becomes a question of interest to ask ourselves how we may find the elementary forces concerned.

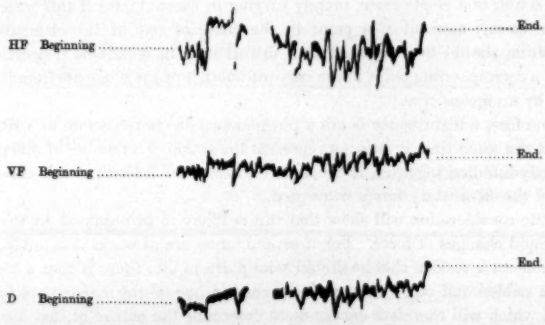
19. A little consideration will show that this is likely to be obtained by the study of small and rapid changes of force. For if several forces are at work, it is unlikely that at the same moment a sudden change should take place in all; there is thus a high probability that a sudden and rapid change is a change in one of the elementary forces concerned, and which will therefore enable us to determine the nature of that force. Even if the change is not a very abrupt one, provided that we confine ourselves to such peaks and hollows as present a similar appearance for all the curves, we may be satisfied that we are observing changes taking place in one only of the elementary disturbing forces; for it is inconceivable that two or more independent forces changing independently should produce similar appearances in all the three curves. This may be illustrated by an example. Suppose, for instance, a disturbance takes place in declination which at the end of one minute has raised the curve one-tenth of an inch, while at the end of the second minute it has fallen again to its original level. Suppose also that a change, precisely the same in nature and amount, takes place in the horizontal force, while in the vertical force the change is only one-twentieth of an inch. Here then we have in our curves three isosceles triangles which, although the last is not, strictly speaking, similar to the other two, yet all three convey the idea of only one force acting. Suppose now another force to have been superimposed which affected the declination very much more than either of the force-components, but which did not begin to work until the end of the first minute. The result would be that the declination peak would be much further

from an isosceles triangle than that of either of the forces; we might even suppose the the descending limb of the declination peak to become level, or even to ascend in consequence of the action of this second force.

The following is a more precise definition of what is requisite before we can refer the action to a pure elementary force.

Let it be supposed that we are comparing together portions of each of the three curves, commencing at the same time, then it may be asserted that these portions are due to the action of a single disturbing force when (the origin for each being the commencement of the portion of the curve under consideration) for equal abscissæ the ordinates of the one curve always bear a definite proportion to those of the other.

20. This is illustrated by the following tracings, which exhibit the movements of the three curves on August 11, 1860, from 2.34 P.M. to 5.26 P.M.



21. From all this we perceive that, in order to find what are the pure elementary forces at work, we must select suitable peaks and hollows, and measure these accurately.

The following Table exhibits the results obtained by comparing such peaks and hollows of the horizontal force with those of the vertical force, no reference being made to the declination.

TABLE IV.—Comparison in length of the Horizontal-force changes with those of the Vertical Force.

Date.	Horizontal-force change (vertical-force change = unity in each instance).	
	Actual measurements.	Mean.
1858. March 2—3	2·4, 2·1, 2·3, 2·0	2·2
March 12—16	1·9, 1·9, 2·1, 1·8, 1·9, 2·3, 2·0, 2·1	2·0
March 27—29	2·3, 1·9, 2·0	2·1
April 9—10	1·9, 2·1, 2·0	2·0
June 23—24	2·3, 2·1, 2·0	2·1
July 5—6	2·1	2·1
1859. February 9—10	1·9, 2·2, 2·2	2·1
February 27—28	1·9, 2·1	2·0
May 19—21	2·0, 1·9, 2·2, 2·1	2·0
June 8—9	2·2, 2·0, 2·0, 2·2, 2·2, 2·0, 2·0 2·1, 1·9, 2·1, 1·9, 1·9, 2·0, 2·1	2·0
July 11—13	2·0, 2·1, 2·1, 1·9, 2·0, 2·2	2·0
August 28—September 7	1·8, 2·0, 2·0, 2·0, 1·9, 1·6, 2·0 2·1, 2·2, 2·2, 2·2, 2·2, 2·0, 2·2 2·3, 1·6, 2·0, 2·0, 2·0, 2·1, 1·8, 1·7 2·0, 1·9, 1·9, 2·1, 1·9, 2·2, 1·9, 1·7, 2·1 2·0, 2·1, 2·0, 2·1, 2·0, 1·9, 2·0, 2·2, 2·0 2·0, 2·0, 2·0	2·0
October 12—18	2·0, 1·9, 1·8, 2·2, 1·9, 2·3, 1·8, 2·0	2·0
December 13—15	2·3, 1·9, 1·8	2·0
1860. March 26—29	2·3, 1·9, 2·0, 1·9, 1·6, 1·8, 1·9, 1·6 2·2, 2·0	1·9
April 9—15	2·1, 2·3, 2·0, 2·1, 1·9, 2·0, 1·8, 2·0 1·8, 2·1	2·0
July 4—6	2·1, 1·9, 2·1, 2·0, 2·0, 2·2, 1·7, 2·3, 2·0	2·0
August 6—12	2·1, 2·0, 2·1, 1·9, 2·1, 1·9, 1·9, 2·2 1·9, 1·9, 2·0, 2·1, 2·0, 2·1, 2·0, 1·9 2·0, 2·0, 1·9, 2·2, 2·1, 1·9, 2·0, 1·9 2·0, 2·2, 1·9, 2·1, 2·0, 2·0	2·0

In this Table the actual measurements have been exhibited in order to afford an idea of the accuracy with which the proportion holds, without attempting to estimate the probable error.

22. In endeavouring to frame a similar Table between the horizontal force and declination, a curious fact presented itself.

Although it is comparatively easy to find changes in the vertical force which are similar to corresponding changes in the horizontal force, yet it is much more difficult to find similar corresponding changes in the horizontal force and declination. Indeed, for many of the cases recorded in the above Table, the declination-change would not be similar to that of either force. It thus appears that, even in cases which do not indicate the action of a pure elementary disturbance, the horizontal-force change preserves an almost invariable relation to that of the vertical force*.

23. The following would appear to be the explanation of this.

Whatever be the nature of an elementary disturbing force, its effect upon the hori-

* This proves, in addition to a physical fact, that these magnetographs are capable of recording with precision the slightest change in either element of the earth's force.

zontal component of the earth's magnetism bears always a nearly invariable proportion to its effect upon the vertical component of the same. In this case it is clear that two or more disturbing forces superimposed would, as far as regards the horizontal and vertical-force changes, behave almost in the same manner as a pure elementary disturbance. This also explains why it is almost impossible to find a peak in the one component of the force corresponding to a hollow in the other.

24. This curious fact may likewise be stated in the following language:—

Whatever be the nature of the disturbing force at work, its resolved portion, which acts in the plane of the magnetic meridian at Kew, is always in nearly the same line.

25. It is very easy to find the direction of this line.

A disturbance of the horizontal force, as it appears in the curve, is, we have seen, very nearly double that of the vertical force. Now an inch in the ordinate of the horizontal-force curve denotes a change amounting to nearly ·010 of the whole force, while for the vertical-force curve it represents a change of ·0025 of the whole; and increasing ordinates denote decreasing force for both elements. Also the absolute value of the horizontal force is 3·8, while that of the vertical force is 9·6.

Hence if we represent by 38 the value of the horizontal component of the disturbing force in the plane of the magnetic meridian, that of the vertical component will be denoted by 12, and the dip of the whole force acting in this plane will be 17°·5 nearly.

26. From what has been already mentioned (art. 22), it may be inferred that it is difficult to obtain similar corresponding changes for all the elements together. The following Table exhibits those instances in which this has been accomplished; but the results can only be regarded as very rough approximations.

In some cases, where the vertical-force disturbance was very small, it was not attempted to measure it.

TABLE V.—Similar corresponding changes for all the elements.

Date.	Greenwich Mean Time.	Character and size of change (vertical-force change = unity in each instance).		
		Declination.	Horizontal force.	Vertical force.
1858.	h m			
March 14.....	2 19 P.M.	rise after =2·1	rise after =1·9	rise after =1·0
15.....	9 53 A.M.	rise after =1·8	rise after =2·0	rise after =1·0
15.....	9 56	fall after =1·7	fall after =1·8	fall after =1·0
15.....	9 35	rise after =2·1	rise after =2·0	rise after
April 9.....	11 14½	rise after =3·1	rise after =2·0	rise after
10.....	4 21	rise after =3·0	rise after =2·0	rise after
10.....	4 23	fall after =2·7	fall after =2·1	fall after =1·0
10.....	6 32½	fall before =3·0	fall before =1·9	fall before =1·0
June 23.....	3 25	fall after =1·4	fall after =2·0	fall after
23.....	3 29	rise after =1·5	rise after =2·0	rise after
23.....	3 33	fall after =1·6	fall after =2·0	fall after
23.....	3 37	rise after =1·6	rise after =2·0	indistinct

TABLE V. (continued).

Date.	Greenwich Mean Time.	Character and size of change (vertical-force change = unity in each instance).		
		Declination.	Horizontal force.	Vertical force.
	h m			
Oct. 28.....	10 59½	hollow =2·0	hollow =2·0	hollow
28.....	11 27½	fall after =2·1	fall after =2·1	fall after =1·0
28.....	11 42 A.M.	fall after =2·0	fall after =2·0	fall after
28.....	1 8½ P.M.	rise after =2·1	rise after =2·0	rise after
Dec. 4.....	11 18 A.M.	rise after =2·0	rise after =2·0	rise after
5.....	8 12	fall before =2·2	fall before =2·1	fall before =1·0
5.....	11 8½	fall after =2·0	fall after =2·0	fall after
5.....	11 11½ A.M.	rise after =2·0	rise after =2·0	indistinct
1859.				
Feb. 26.....	12 53½ P.M.	fall after =2·1	fall after =2·0	fall after
26.....	1 59½ P.M.	peak =2·2	peak =2·0	peak
27.....	3 12½ A.M.	hollow =2·0	hollow =2·0	hollow
27.....	3 47½ A.M.	peak =2·2	peak =2·0	peak
27.....	3 8½ P.M.	fall after =2·2	fall after =1·9	fall after =1·0
27.....	3 12½	rise after =2·7	rise after =2·2	rise after =1·0
June 8.....	11 43½	rise after =2·5	rise after =2·2	rise after =1·0
8.....	11 59½ P.M.	peak =2·3	peak =2·0	peak
9.....	11 7½ A.M.	fall after =2·1	fall after =2·1	fall after =1·0
Sept. 1.....	11 16 A.M.	*fall after* =1·4	rise after =1·9	rise after =1·0
4.....	2 14 P.M.	rise after =1·2	rise after =2·2	rise after =1·0
Oct. 17.....	11 42 P.M.	fall after =3·0	fall after =2·0	fall after =1·0
18.....	12 31 A.M.	fall after =3·2	fall after =2·0	fall after =1·0
18.....	12 39	fall after =3·1	fall after =2·1	fall after =1·0
18.....	8 21 A.M.	fall after =2·6	fall after =2·0	fall after
Dec. 14.....	12 7½ P.M.	rise after =2·4	rise after =2·0	rise after
14.....	12 18 P.M.	rise after =2·5	rise after =2·0	rise after =1·0
1860.				
April 10.....	5 15½ A.M.	rise after =2·7	rise after =1·9	rise after =1·0
10.....	5 20½	fall after =3·2	fall after =2·0	fall after
10.....	5 22	rise after =2·9	rise after =2·0	rise after =1·0
10.....	6 3	fall after =3·3	fall after =2·0	fall after =1·0
10.....	6 7 A.M.	rise after =3·3	rise after =2·0	rise after =1·0
13.....	12 54½ P.M.	rise after =2·9	rise after =1·9	rise after =1·0
July 5.....	3 20 A.M.	fall after =3·6	fall after =2·1	fall after =1·0
5.....	4 34	fall after =3·5	fall after =2·1	fall after =1·0
5.....	7 21½	fall after =2·8	fall after =1·7	fall after =1·0
5.....	8 10 A.M.	peak =3·4	peak =2·1	peak =1·0
Aug. 10.....	6 57½ P.M.	fall after =1·1	fall after =2·2	fall after =1·0
10.....	7 1½	rise after =1·2	rise after =2·2	rise after =1·0
11.....	4 18	fall after =1·1	fall after =2·0	fall after =1·0
11.....	4 21	rise after =0·9	rise after =1·7	rise after =1·0
11.....	4 25½	fall after =0·8	fall after =2·1	fall after =1·0
11.....	4 29	rise after =1·1	rise after =2·0	rise after =1·0
11.....	4 31	fall after =1·1	fall after =1·8	fall after =1·0
11.....	4 36½	rise after =1·0	rise after =2·1	rise after =1·0
11.....	4 39	fall after =1·1	fall after =1·8	fall after =1·0
11.....	4 41 P.M.	rise after =1·0	rise after =1·7	rise after =1·0

27. It appears from this Table that the proportional value of the declination-element is very nearly constant during a disturbance, but that it varies much from one disturbance to another. The constancy of this element during the same disturbance will perhaps be best seen by comparing the values in the declination column with those in the column of the horizontal force, as the vertical-force changes being small, any error of measurement is very apt to alter the proportion between them and the larger changes with which they are compared.

28. It will also be noticed that the great disturbance of August—September 1859 seems to consist of two disturbances superimposed, one being of the normal type, but the other, as regards the declination-element, being decidedly abnormal. This agrees well with the results of Table III.

29. It would thus appear that in the great majority of cases only one type or group of forces operates in producing a disturbance, and that the various individual forces which compose this group have a very small range as regards their mode of action upon the three elements of the earth's magnetism at Kew. We may therefore (approximately at least) represent a disturbance by a single force; and for this purpose it is competent for us to average for each disturbance the results of Table V.

30. Now that force which affects the declination is evidently the horizontal component of the disturbing magnetic force which acts in a direction perpendicular to the magnetic meridian, and its value will be $\mathbf{X} \tan \partial\theta$, where $\mathbf{X}$ denotes the absolute horizontal force, and $\partial\theta$ the angular displacement of the declination magnet. But an inch of the declination-ordinate represents 22′, hence the disturbing force which would cause a change to this amount will be $= 3{\cdot}8 \tan 22' = {\cdot}024$, while, as we have already seen, an inch of change in the horizontal-force ordinate denotes a disturbing force $= {\cdot}038$. Again, decreasing ordinates represent increasing westerly declination; and since (except in one case) the three curves are simultaneously affected in the same direction, it follows that (with the same exception) a magnetic force acting from magnetic south to north must be compounded with one acting from magnetic east to west, and with one acting vertically downwards. But, for the anomalous disturbance of August—September 1859, a force acting from magnetic south to north must be compounded with one acting from magnetic west to east.

Applying now the ordinary rules for combining forces, we obtain the following Table, in which the astronomical azimuth and dip of the various disturbing forces are given.

31. It will, however, be first necessary to allude to a peculiarity in this method of determining the direction of the disturbing force. This is, that our results apply in strictness only to those small and rapid changes which occur as it were on the surface of the great disturbance-wave.

We might, for instance, be engaged in studying the direction of that force which would occasion a small depression which we had observed to occur simultaneously in the three curves, while at the same time these curves might be elevated above their normals, and not depressed by the main body of the disturbing force. We have, however, in art. 15 given grounds for supposing that these small and rapid peaks and hollows denote

changes in the main body of the disturbing force. Our results regarding the peaks and hollows may therefore, perhaps, be viewed as applicable to the main body of the force; but we must bear in mind that while we may thus be enabled to determine the resultant line of action of this force, we do not yet learn whether it is of a positive or negative nature, whether it may be represented by a north or by a south pole. This will be rendered evident when we reflect that a small depression may be due either to the weakening of an elevating force, or to the strengthening of one of an opposite character. It thus appears that the north or south nature of the whole distubing force must be determined by reference to the general appearance of the curve. Indeed it will be afterwards shown that we have grounds for supposing two antagonistic forces to be in operation at once. To fix our thoughts, however, let us suppose for the following Table the disturbing force to be one which increases the earth's horizontal intensity at Kew, and let us consider its action on the north pole of the needle.

TABLE VI.—Representing the Astronomical Azimuth and Dip of the various disturbing forces.

Date of disturbance.	Direction in which the force tends to make the north pole of a needle point.	Dip which the force would give to the north pole of a needle.
1858. March 14—15	North 53° 46·5′ West	15° 30·5′
April 9—10	64 28·5	13 0·5
June 23	47 13	15 53
October 28	54 5·5	14 43·5
December 4—5	54 5·5	14 43·5
1859. February 26—27	56 27·5	14 23·5
June 8—9	56 10·5 West	13 53·5
September 1—4	3 27·5 East	16 46
September 1—4	40 30·5 West	15 11
October 17—18	64 21·5	12 52·5
December 14	59 13·5	14 1·5
1860. April 10—13	65 54	12 55
July 5	67 54	12 17
August 10—11	North 40 1·5 West	16 59·5

32. It has been already mentioned that we do not ascertain by our method whether the whole disturbing force is positive or negative. The following considerations, however, may serve to elucidate this subject.

We have seen in art. 18 that a disturbance cannot be represented by the action of a single force, and we have also seen (art. 29) that the various forces which compose a disturbing group have a very small range as regards their mode of action upon the three elements, this range being especially small when the two force-elements are compared together.

We might therefore hope to find, on inspecting the general appearance of the curves, that the two force-elements are simultaneously raised or depressed with reference to their normals nearly in the proportion denoted by the nature of the disturbing force whose character we have been analysing.

But this is not often the case; and although generally both elements are on the same side of their normals, yet it happens occasionally that the one element is above while the other is below; while on such occasions there is nothing in the behaviour of the peaks and hollows to indicate the action of any other than the ordinary disturbing force.

33. This may perhaps be explained by supposing two antagonistic forces to be in operation at once, the one tending to elevate, and the other to depress the curve, the absolute values of these forces bearing a somewhat large proportion to their differences, and the one force affecting the elements in a slightly different manner from the other.

Suppose, for instance, that $+1$ and -1 denote the position of the horizontal and the vertical-force curves at the same moment, the former being elevated above its normal, and the latter depressed below it.

Conceive this result due to the action of an elevating force represented by $+40$ $+20$ opposed by a depressing one represented by -39 -21, and we have a sufficient explanation of this anomalous circumstance, while at the same time both the antagonistic forces sufficiently present the normal type.

34. The same style of reasoning will apply in comparing the declination curve with that of either force; only here we must suppose that the one force affects the declination in a somewhat different manner from its antagonist, so that the proportion between a declination peak and one of either force is not so constant as that between peaks of the two forces. The idea of two antagonistic forces, the difference of which represents the visible action, seems also to give the simplest explanation of the fact, that sometimes a force which depresses one of the elements will change in the course of a few hours to one which elevates it—since otherwise we must suppose the disturbing force to have changed its character.

This also is the view of disturbing forces which General SABINE, who has studied the subject so long and so successfully, has lately been disposed to adopt on other grounds; and I am happy to think that the idea herein advocated is that of one whose judgment is so mature and whose information is so extensive.

35. Adopting this view of the subject, it is worthy of remark that the same element of the disturbing forces (the declination) which changes so much its comparative value from one disturbance to another, changes also the most of the three when we pass from the one to the other of the antagonistic forces concerned in the same disturbance.

In conclusion, I may be allowed to state that this paper is submitted to the Royal Society rather as indicating a method of analysis than as embodying the results of an investigation.

Note on the Electromotive Force induced in the Earth's Crust by Variations of Terrestrial Magnetism. *By Prof.* W. THOMSON, *A.M., L.L.D., F.R.S.*

The evidence from observation adduced in the preceding paper tending to show that some "earth-currents" which have been actually observed have been the electro-magnetically induced effects of variations of terrestrial magnetism, appears to be a very important contribution to the discovery of the complete theory of these most interesting and perplexing phenomena. It necessarily, however, suggests the question, Is the electromotive force induced by variations of terrestrial magnetism comparable in amount with that which is found in observations on earth-currents? There is scarcely occasion at present for working out a complete mathematical theory of the currents induced in the earth's crust by any fully specified magnetic variations. This can easily be done as soon as observation supplies data enough to make it useful. In the mean time a very rough theoretical estimate of the absolute amount of electromotive force induced by such magnetic variations as we know to exist, is sufficient to render it certain that this electro-magnetic induction does very sensibly influence the observed phenomena of earth-currents. For if there be, as we know there is every day, a gradual variation of terrestrial magnetism over a large portion of the earth's surface, amounting to a minute of angle in the direction of the dipping-needle, or to some thousandths, or not much less than one thousandth of force during several hours, this change of magnetism must induce in a length of a few hundred miles in the earth's crust an electromotive force, which we readily see must be comparable with that which would be induced in a linear conductor of the same length if carried across the lines of magnetic force at the rate of a minute of arc (or a nautical mile) in several hours. In two articles communicated eleven years ago to the 'Philosophical Magazine'*, I explained the principles on which such an electromotive force as this is to be compared with familiar standards, as, for instance, that of an element of DANIELL's battery. Thus a horizontal conductor, 1,400,000 feet long (or about 270 British statute miles), carried at the rate of 600 feet (or about one-tenth of a minute of arc) per hour in a horizontal direction perpendicular to its own length across the British Isles or neighbouring Atlantic ocean (where the vertical magnetic force averages about 10 British absolute units of magnetic force), would experience an induced electromotive force amounting to $\frac{600}{3600} \times 10 \times 1{,}400{,}000$, or about 2,300,000 British absolute units of electromotive force. But, as I showed in the second of those articles, the electromotive force of a single cell of DANIELL's is about 2,500,000 British absolute units. Hence the induced electro-magnetic force in question is about equal to that of a single cell. Some such electromotive force as this, therefore, must be induced in a length of 270 miles of the earth's crust, by the ordinary diurnal variations of terrestrial magnetism; and the much more rapid variations in magnetic storms

* See 1851, Second half year. "On the Mechanical Theory of Electrolysis," and "Applications of the Principle of Mechanical Effect to the Measurement of Electromotive Forces, and of Galvanic Resistances, in Absolute Units."

must produce much greater electromotive forces, which we may conceive may not unfrequently be as much as that of ten or twenty cells, and sometimes may amount to 100 cells or more. Just such amounts of electromotive force were those which I actually observed in the Atlantic cable, as the following extract from the 'Encyclopædia Metropolitana,' article "Telegraph, electric," shows.

"In the failure of the Atlantic Cable in September 1858, the portion terminating at Valencia came to give nearly the same indications as an insulated conductor about 270 miles long, laid out westward, and connected with a copper plate sunk at a little less than that distance in the Atlantic. In these circumstances the writer found that from 1 to 9 or 10 twentieths of the electromotive force of two DANIELL'S elements was generally sufficient to balance the earth-current; not unfrequently 14 or 15 were required; sometimes, although rarely, 20, or the full electromotive force of two DANIELL'S elements, was insufficient; and once or twice in the course of the month of September, earth-currents were received so strong that five or six DANIELL'S elements would have been required to balance them."

It seems therefore quite certain that the ordinary every-day earth-currents in that locality must be very sensibly influenced by electro-magnetic induction from the ordinary diurnal variations of terrestrial magnetism; but it is also quite certain that they are only in part due to this cause, and that some more powerful, but as yet unknown agency, is at work to produce them. For although I found that a day seldom, if ever, passes without the direction of the current changing several times, yet there was no relation between the times of such changes and the solar hours. I conclude with the following additional extract from the same article, expressing views regarding earth-currents which I think will be found to agree with the extensive and careful observations of Mr. C. V. WALKER, which have been published since it was written, although they seem quite at variance with the theory which has recently been advocated by Prof. LAMONT and Dr. LLOYD, that earth-currents, however they are themselves generated, do directly produce the magnetic variations.

"Earth-currents are certainly related to the irregular variations of terrestrial magnetism, since they are always found unusually strong during brilliant displays of aurora borealis; for it has long been known that, on these occasions, the magnetic disturbances are unusually strong. Being related to the variations of terrestrial magnetism, it is probable that the earth-currents also will be found to have daily periods; but, in the mean time, we only know that, while the diurnal variation in terrestrial magnetism is observable in general every day, and is only on rare occasions overborne by irregular disturbances, the earth-currents vary each day from hour to hour, like the wind, under some overpowering non-periodic influence, and can only show daily periodicity in residual averages derived from lengthened series of observations. It is probable that careful synchronous observations of auroras, earth-currents, and variations of terrestrial magnetism, will lead to a discovery of the primary influence, whether in the earth, or terrestrial atmosphere, or surrounding interplanetary air, which causes these phenomena."—W. T.

XXIX. *On the Analytical Theory of the Conic.* By Arthur Cayley, *F.R.S.*

Received May 8,—Read May 15, 1862.

The decomposition into its linear factors of a decomposable quadric function cannot be effected in a symmetrical manner otherwise than by formulæ containing supernumerary arbitrary quantities; thus, for a binary quadric (which of course is always decomposable) we have

$$(a, b, c\text{)(}x, y)^2 = \frac{1}{(a, b, c\text{)(}x', y')^2} \text{ Prod. } \{(a, b, c\text{)(}x, y\text{)(}x', y') \pm \sqrt{ac-b^2}(xy'-x'y)\};$$

or the expression for a linear factor is

$$\frac{1}{\sqrt{(a, b, c\text{)(}x', y')^2}}\{(a, b, c\text{)(}x, y\text{)(}x', y') \pm \sqrt{ac-b^2}(xy'-x'y)\},$$

which involves the arbitrary quantities (x', y'). And this appears to be the reason why, in the analytical theory of the conic, the questions which involve the decomposition of a decomposable ternary quadric have been little or scarcely at all considered: thus, for instance, the expressions for the coordinates of the points of intersection of a conic by a line (or say the line-equations of the two ineunts), and the equations for the tangents (separate each from the other) drawn from a given point not on the conic, do not appear to have been obtained. These questions depend on the decomposition of a decomposable ternary quadric, which decomposition itself depends on that for the simplest case, when the quadric is a perfect square. Or we may say that in the first instance they depend on the transformation of a given quadric function $U=(*\text{)(}x, y, z)^2$ into the form W^2+V, where W is a linear function, given save as to a constant factor (that is, $W=0$ is the equation of a given line), and V is a decomposable quadric function, which is ultimately decomposed into its linear factors, $=QR$, so that we have $U=W^2+QR$. The formula for this purpose, which is exhibited in the eight different forms I, II, III, IV, I(bis), II(bis), III(bis), IV(bis), is the analytical basis of the whole theory; and the greater part of the memoir relates to the establishment of these forms.

The solution of the geometrical questions above referred to is (as shown in the memoir) involved in and given immediately by these forms. It is also shown that the formulæ are greatly simplified in the case *e. g.* of tangents drawn to a conic from a point in a conic having double contact with the first-mentioned conic, and that in this case they lead to the linear Automorphic Transformation of the ternary quadric. The memoir concludes with some formulæ relating to the case of two conics, which however is treated of in only a cursory manner.

Article Nos. 1 to 17, relating to a single conic.

1. The point-equation of the conic is

$$(a, b, c, f, g, h)(x, y, z)^2=0,$$

which expresses that the point (x, y, z) is an ineunt of the conic.

The line-equation of the same conic is

$$\begin{vmatrix} & \xi, & \eta, & \zeta \\ \xi & a, & h, & g \\ \eta & h, & b, & f \\ \zeta & g, & f, & c \end{vmatrix} =0,$$

or putting

$$(A, B, C, F, G, H)=(bc-f^2, ca-g^2, ab-h^2, gh-af, hf-bg, fg-ch),$$

the line-equation is

$$(A, B, C, F, G, H)(\xi, \eta, \zeta)^2=0,$$

which expresses that the line (ξ, η, ζ) (that is, the line the point-equation whereof is $\xi x+\eta y+\zeta z=0$) is a tangent of the conic. We are thus in the analytical theory of the conic concerned with the quadrics $(a, b, c, f, g, h)(x, y, z)^2$ and $(A, B, C, F, G, H)(\xi, \eta, \zeta)^2$, which are the characteristics or *nilfactums* of these equations respectively.

2. I put also

$$K=\begin{vmatrix} a, & h, & g \\ h, & b, & f \\ g, & f, & c \end{vmatrix},$$

or, what is the same thing,

$$K=abc-af^2-bg^2-ch^2+2fgh.$$

3. It may be convenient to notice that when $(a, \ldots)(x, y, z)^2$ breaks up into factors, the conic the equation whereof is $(a, \ldots)(x, y, z)^2=0$, becomes a pair of lines; and that when $(a, \ldots)(x, y, z)^2$ is a perfect square, the conic becomes a pair of coincident lines, or say a *twofold* line. But a pair of lines, distinct or coincident, cannot be represented by a line-equation. The analytical formulæ presently given show that in the former case $(A, \ldots)(\xi, \eta, \zeta)^2$ is the square of a linear function, which equated to zero gives the line-equation of the point of intersection of the two lines, or node of the conic; and the equation $(A, \ldots)(\xi, \eta, \zeta)^2=0$ accordingly represents such point considered as a pair of coincident points, or say a *twofold* point. But in the latter case, where the conic is a twofold line, $(A, \ldots)(\xi, \eta, \zeta)^2$ is identically equal to zero, and the line-equation $(A, \ldots)(\xi, \eta, \zeta)^2=0$ is a mere identity $0=0$, thus ceasing to have any signification at all. And the like remarks apply to the conic as represented by the line-equation $(A, \ldots)(\xi, \eta, \zeta)^2=0$, the conic here breaking up into a pair of distinct or coincident points, &c.

4. It is proper to remark also that

$$(a, \ldots)(x', y', z')(x, y, z)=0$$

is the equation of the polar of the point (x', y', z') in regard to the conic, and that

$$(\mathrm{A}, ..)(\xi, \eta', \zeta')(\xi, \eta, \zeta)=0$$

is the line-equation of the pole of the line (ξ, η', ζ'); or, what is the same thing, the point-coordinates of the pole are

$$\mathrm{A}\xi+\mathrm{H}\eta'+\mathrm{G}\zeta' : \mathrm{H}\xi'+\mathrm{B}\eta'+\mathrm{F}\zeta' : \mathrm{G}\xi+\mathrm{F}\eta'+\mathrm{C}\zeta'.$$

5. The inverse matrix is

$$\begin{pmatrix} a, & h, & g \\ h, & b, & f \\ g, & f, & c \end{pmatrix}^{-1} = \frac{1}{\mathrm{K}} \begin{pmatrix} \mathrm{A}, & \mathrm{H}, & \mathrm{G} \\ \mathrm{H}, & \mathrm{B}, & \mathrm{F} \\ \mathrm{G}, & \mathrm{F}, & \mathrm{C} \end{pmatrix};$$

but it is convenient to disregard the factor $\frac{1}{\mathrm{K}}$, and speak of (A, B, C, F, G, H) as the inverse or reciprocal coefficients. The equation just written down implies the relations $\mathrm{A}a+\mathrm{H}h+\mathrm{G}g=\mathrm{K}$, $\mathrm{A}h+\mathrm{H}b+\mathrm{G}f=0$, &c., which may be arranged in two different ways as a system of nine equations.

6. We have also

$$(\mathrm{BC}-\mathrm{F}^2, \mathrm{CA}-\mathrm{G}^2, \mathrm{AB}-\mathrm{H}^2, \mathrm{GH}-\mathrm{AF}, \mathrm{HF}-\mathrm{BG}, \mathrm{FG}-\mathrm{CH})=\mathrm{K}(a, b, c, f, g, h),$$

and

$$\mathrm{ABC}-\mathrm{AF}^2-\mathrm{BG}^2-\mathrm{CH}^2+2\mathrm{FGH}=\mathrm{K}^2,$$

which are well-known theorems.

7. I notice also the theorem

$$(a, ..)(x, y, z)^2.(a, ..)(x', y', z')^2-[(a, ..)(x, y, z)(x', y', z')]^2$$
$$=(\mathrm{A}, ..)(yz'-y'z, zx'-z'x, xy'-x'y)^2,$$

which is much used in the sequel: it may be mentioned, in passing, that this is included in the more general theorem

$$\begin{vmatrix} (a, .)(x, y, z)(l, m, n), & (a, ..)(x', y', z')(l, m, n) \\ (a, ..)(x, y, z)(l', m', n'), & (a, ..)(x', y', z')(l, m, n) \end{vmatrix}$$
$$=(\mathrm{A}, ..)(yz'-y'z, zx'-z'x, xy'-x'y)(mn'-m'n, nl'-n'l, lm'-l'm),$$

which is at once deducible from

$$\begin{vmatrix} \mathrm{L}l+\mathrm{M}m+\mathrm{N}n, & \mathrm{L}'l+\mathrm{M}'m+\mathrm{N}'n \\ \mathrm{L}l'+\mathrm{M}m'+\mathrm{N}n', & \mathrm{L}'l'+\mathrm{M}'m'+\mathrm{N}'n' \end{vmatrix}$$
$$=(\mathrm{MN}'-\mathrm{M}'\mathrm{N})(mn'-m'n)+(\mathrm{NL}'-\mathrm{N}'\mathrm{L})(nl'-n'l)+(\mathrm{LM}'-\mathrm{L}'\mathrm{M})(lm'-l'm),$$

by writing therein

$$(\mathrm{L}, \mathrm{M}, \mathrm{N})=(ax+hy+gz, hx+by+fz, gx+fy+cz),$$
$$(\mathrm{L}', \mathrm{M}', \mathrm{N}')=(ax'+hy'+gz', hx'+by'+fz', gx'+fy'+cz').$$

8. Suppose now that

$$(a, b, c, f, g, h)(x, y, z)^2$$

breaks up into factors, or say that we have

$$(a, b, c, f, g, h)(x, y, z)^2 = 2(\alpha x+\beta y+\gamma z)(\alpha' x+\beta' y+\gamma' z),$$

the values of the coefficients $(a, ..)$ then are

$$(a, b, c, f, g, h) = (2a\alpha', 2\beta\beta', 2\gamma\gamma', \beta\gamma'+\beta'\gamma, \gamma\alpha'+\gamma'\alpha, \alpha\beta'+\alpha'\beta),$$

and forming from these the inverse coefficients $(A, ..)$ and the discriminant K, we find

$$(A, B, C, F, G, H) = -(\beta\gamma'-\beta'\gamma, \gamma\alpha'-\gamma'\alpha, \alpha\beta'-\alpha'\beta)^2.$$

$$K=0.$$

9. The last-mentioned equation, $K=0$, is the condition in order that $(a, ..)(x, y, z)^2$ may break up into factors; and when it does so, we have

$$(A, ..)(\xi, \eta, \zeta)^2 = -[(\beta\gamma'-\beta'\gamma, \gamma\alpha'-\gamma'\alpha, \alpha\beta'-\alpha'\beta)(\xi, \eta, \zeta)]^2,$$

that is, $(a, ..)(x, y, z)^2$ breaking up into factors, $(A, ..)(\xi, \eta, \zeta)^2$ is a perfect square; and equating it to zero, we have

$$[(\beta\gamma'-\beta'\gamma, \gamma\alpha'-\gamma'\alpha, \alpha\beta'-\alpha'\beta)(\xi, \eta, \zeta)]^2 = 0;$$

which, (ξ, η, ζ) being line-coordinates, gives (as a twofold point) the point of intersection of the lines (α, β, γ), $(\alpha', \beta', \gamma')$, that is, the lines $\alpha x+\beta y+\gamma z=0$, $\alpha' x+\beta' y+\gamma' z=0$.

10. If $(a, ..)(x, y, z)^2$ is a perfect square, then $\alpha' : \beta' : \gamma' = \alpha : \beta : \gamma$; whence not only, as before, $K=0$, but the coefficients (A, B, C, F, G, H) all vanish (this implies the first-mentioned condition, $K=0$); and the line-equation $(A, ..)(\xi, \eta, \zeta)^2=0$ becomes the mere identity $0=0$.

11. Conversely if $K=0$, then $(a, ..)(x, y, z)^2$ breaks up into factors; and if (A, B, C, F, G, H) all vanish, then $(a, ..)(x, y, z)^2$ is a perfect square. The conclusions stated *ante*, No. 3, are thus sustained.

12. I assume, first, that $(a, ..)(x, y, z)^2$ is a perfect square (No. 13); and secondly, that it breaks up into factors (No. 14); and I proceed to inquire how in the one case the root, and in the other case the factors, can be determined in a symmetrical form.

13. Considering the before-mentioned identical equation

$$(a, ..)(x, y, z)^2 . (a, ..)(x', y', z')^2 - [(a, ..)(x, y, z)(x', y', z')]^2 = (A, ..)(yz'-y'z, zx'-z'x, xy'-x'y)^2,$$

if $(a, ..)(x, y, z)^2$ is a perfect square, then by what precedes, the right-hand side of the equation vanishes, and we have

$$(a, ..)(x, y, z)^2 = \frac{[(a, ..)(x, y, z)(x', y', z')]^2}{(a, ..)(x', y', z')^2};$$

and the root of $(a, ..)(x, y, z)^2$ is thus seen to be

$$= \pm \frac{(a, ..)(x, y, z)(x', y', z')}{\sqrt{(a, ..)(x', y', z')^2}},$$

an expression which involves the quantities (x', y', z'), the values whereof may be assumed

at pleasure without altering the value of the expression. For instance, assuming for (x', y', z') the values (1, 0, 0), (0, 1, 0), (0, 0, 1) successively, the different values of the expression are

$$\frac{ax+hy+gz}{\sqrt{a}}, \quad \frac{hx+by+fz}{\sqrt{b}}, \quad \frac{gx+fy+cz}{\sqrt{c}}.$$

But if, as assumed, $(a, ..\chi x, y, z)^2$ be a perfect square $=(\alpha x+\beta y+\gamma z)^2$, then

$$(a, b, c, f, g, h)=(\alpha^2, \beta^2, \gamma^2, \beta\gamma, \gamma\alpha, \alpha\beta),$$

and each of the foregoing values becomes equal to the root $\alpha x+\beta y+\gamma z$. It is somewhat singular that it is not possible to obtain symmetrical formulæ without employing in this manner supernumerary arbitrary quantities such as (x', y', z').

14. Next, if $(a, \ldots\chi x, y, z)^2$, instead of being a perfect square, only breaks up into factors, then in the foregoing identical equation the right-hand side is a perfect square, and by the formula just obtained its value is

$$\frac{[(A, ..\chi X, Y, Z\chi yz'-y'z, zx'-z'x, xy'-x'y)]^2}{(A, ..\chi X, Y, Z)^2},$$

where (X, Y, Z) are supernumerary arbitrary quantities. The identical equation then gives

$$(a, ..\chi x, y, z)^2=\frac{1}{(a, \ldots\chi x', y', z')^2}\left\{[(a, ..\chi x, y, z\chi x', y', z')]^2+\frac{[(A, ..\chi X, Y, Z\chi yz'-y'z, zx'-z'x, xy'-x'y)]^2}{(A, ..\chi X, X, Z)^2}\right\},$$

and consequently

$$(a, ..\chi x, y, z)^2=\frac{1}{(a, ..\chi x', y', z')^2} \text{ Product of}$$

$$\left\{(a, ..\chi x, y, z\chi x', y', z')\pm\frac{(A, ..\chi X, Y, Z\chi yz'-y'z, zx'-z'x, xy'-x'y)}{\sqrt{-(A, ..\chi X, Y, Z)^2}}\right\},$$

a formula which exhibits the decomposition of $(a, ..\chi x, y, z)^2$ assumed to be a function which breaks up into factors; the formula contains the two sets of supernumerary arbitrary quantities (x', y', z') and (X, Y, Z). It will be remembered that (A, ..) denotes the system of inverse or reciprocal coefficients $(bc-f^2, \ldots)$.

15. Consider the formula

$$(a, b, c, f, g, h\chi\eta\zeta'-\eta'\zeta, \zeta\xi'-\zeta'\xi, \xi\eta'-\xi'\eta)^2=(a, b, c, f, g, h\chi\xi', \eta', \zeta')^2,$$

which gives

$$\begin{aligned}
a&= c\eta^2+b\zeta^2-2f\eta\zeta,\\
b&= a\zeta^2+c\xi^2-2g\zeta\xi,\\
c&= b\xi^2+a\eta^2-2h\xi\eta,\\
f&=-a\eta\zeta-f\xi^2+g\xi\eta+h\xi\zeta,\\
g&=-b\zeta\xi+f\xi\eta-g\eta^2+h\eta\zeta,\\
h&=-c\xi\eta+f\xi\zeta+g\eta\zeta-h\zeta^2;
\end{aligned}$$

and from these we deduce

$$\begin{vmatrix} a, & h, & g \\ h, & b, & f \\ g, & f, & c \end{vmatrix} (\xi, \eta, \zeta) = (0, 0, 0),$$

viz. $a\xi+h\eta+g\zeta=0$, &c.

Also

$$(bc-f^2,\ ca-g^2,\ ab-h^2,\ gh-af,\ hf-bg,\ fg-ch) = (\xi, \eta, \zeta)^2.(A, B, C, F, G, H)(\xi, \eta, \zeta)^2,$$

that is,

$$bc-f^2 = \xi^2(A, B, C, F, G, H)(\xi, \eta, \zeta)^2, \text{ &c.}$$

Whence also

$$(bc-f^2, \ldots)(l, m, n)^2 = (l\xi+m\eta+n\zeta)^2 (A, \ldots)(\xi, \eta, \zeta)^2,$$

and

$$(bc-f^2, \ldots)(l, m, n)(l', m', n') = (l\xi+m\eta+n\zeta)(l'\xi+m'\eta+n'\zeta)(A, \ldots)(\xi, \eta, \zeta)^2;$$

and moreover

$$abc-af^2-bg^2-ch^2+2fgh=0.$$

16. The last equation shows that $(a, \ldots)(\eta\zeta'-\eta'\zeta,\ \zeta\xi'-\zeta'\xi,\ \xi\eta'-\xi'\eta)^2$, considered as a function of (ξ', η', ζ'), breaks up into factors. Or since the expression is not altered by interchanging (ξ', η', ζ') and (ξ, η, ζ), the same expression, considered as a function of (ξ, η, ζ), breaks up into factors. It is in fact easy to see that any quantic whatever, $(*)(\eta\zeta'-\eta'\zeta,\ \zeta\xi'-\zeta'\xi,\ \xi\eta'-\xi'\eta)^m$, considered as a function of (ξ, η, ζ), breaks up into linear factors; for in virtue of the equation $\xi'(\eta\zeta'-\eta'\zeta)+\eta'(\zeta\xi'-\zeta'\xi)+\zeta'(\xi\eta'-\xi'\eta)=0$, any one of the quantities $\eta\zeta'-\eta'\zeta$, $\zeta\xi'-\zeta'\xi$, $\xi\eta'-\xi'\eta$ can be expressed as a linear function of the other two; so that the quantic can be expressed as a linear function of any two of the three quantities; and *quà* homogeneous function of two quantities, it of course breaks up into factors, linear functions of these two quantities.

We may in all the formulæ interchange (x', y', z') and (x, y, z), writing (a', b', c', f', g', h') in the place of (a, b, c, f, g, h).

17. Putting, in like manner,

$$(A, B, C, F, G, H)(yz'-y'z,\ zx'-z'x,\ xy'-x'y)^2 = (\mathfrak{A}, \mathfrak{B}, \mathfrak{C}, \mathfrak{F}, \mathfrak{G}, \mathfrak{H})(x', y', z')^2,$$

so that

$$\begin{aligned} \mathfrak{A} &= Cy^2+Bz^2-2Fyz, \\ \mathfrak{B} &= Ax^2+Cz^2-2Gzx, \\ \mathfrak{C} &= Bx^2+Ay^2-2Hxy, \\ \mathfrak{F} &= -Ayz-Fx^2+Gxy+Hzx, \\ \mathfrak{G} &= -Bzx+Fxy-Gy^2+Hyz, \\ \mathfrak{H} &= -Cxy+Fzx+Gyz-Hz^2, \end{aligned}$$

we obtain

$$\begin{vmatrix} \mathfrak{A}, & \mathfrak{H}, & \mathfrak{G} \\ \mathfrak{H}, & \mathfrak{B}, & \mathfrak{F} \\ \mathfrak{G}, & \mathfrak{F}, & \mathfrak{C} \end{vmatrix} (x, y, z) = (0, 0, 0),$$

viz. $\mathfrak{A}x+\mathfrak{H}y+\mathfrak{G}z=0$, &c.

Also

$$(\mathfrak{B}\mathfrak{C}-\mathfrak{F}^2,\ \mathfrak{C}\mathfrak{A}-\mathfrak{G}^2,\ \mathfrak{A}\mathfrak{B}-\mathfrak{H}^2,\ \mathfrak{G}\mathfrak{H}-\mathfrak{A}\mathfrak{F},\ \mathfrak{H}\mathfrak{F}-\mathfrak{B}\mathfrak{G},\ \mathfrak{F}\mathfrak{G}-\mathfrak{C}\mathfrak{H})$$
$$=(x, y, z)^2.\,\mathrm{K}(a, b, c, f, g, h)(x, y, z)^2;$$

that is,

$$\mathfrak{B}\mathfrak{C}-\mathfrak{F}^2=x^2\mathrm{K}(a, b, c, f, g, h)(x, y, z)^2,\ \&c.;$$

whence also

$$(\mathfrak{B}\mathfrak{C}-\mathfrak{F}^2, ..)(\lambda, \mu, \nu)^2=(\lambda x+\mu y+\nu z)^2.\,\mathrm{K}(a, ..)(x, y, z)^2,$$
$$(\mathfrak{B}\mathfrak{C}-\mathfrak{F}^2, ..)(\lambda, \mu, \nu)(\lambda', \mu', \nu')=(\lambda x+\mu y+\nu z)(\lambda' x+\mu' y+\nu' z).\,\mathrm{K}(a, ..)(x, y, z)^2;$$

and moreover

$$\mathfrak{A}\mathfrak{B}\mathfrak{C}-\mathfrak{A}\mathfrak{F}^2-\mathfrak{B}\mathfrak{G}^2-\mathfrak{C}\mathfrak{H}^2+2\mathfrak{F}\mathfrak{G}\mathfrak{H}=0.$$

The last equation shows that $(A, ..)(yz'-y'z, zx'-z'x, xy'-x'y)^2$, considered as a function of (x', y', z'), breaks up into factors, or (what is the same thing) this expression, considered as a function of (x, y, z), breaks up into factors; we may in all the formulæ interchange (x, y, z) and (x', y', z'), writing $(\mathfrak{A}', \mathfrak{B}', \mathfrak{C}', \mathfrak{F}', \mathfrak{G}', \mathfrak{H}')$ in the place of $(\mathfrak{A}, \mathfrak{B}, \mathfrak{C}, \mathfrak{F}, \mathfrak{G}, \mathfrak{H})$.

Article Nos. 18 to 28, relating to a single conic in connexion with a point or line.

18. I apply the decomposition formula to the function $(A, ..)(yz'-y'z, ..)^2$, which, considered as a function of (x, y, z), breaks up into factors. We have

$$(A, ..)(yz'-y'z, ..)^2=(\mathfrak{A}', ..)(x, y, z)^2$$
$$=\frac{1}{(\mathfrak{A}', ..)(l, m, n)^2}\ \text{Product of}$$
$$\left\{(\mathfrak{A}', ..)(l, m, n)(x, y, z)\pm\frac{(\mathfrak{B}'\mathfrak{C}'-\mathfrak{F}'^2, ..)(mz-ny, ..)(\lambda, \mu, \nu)}{\sqrt{-(\mathfrak{B}'\mathfrak{C}'-\mathfrak{F}'^2, ..)(\lambda, \mu, \nu)^2}}\right\}.$$

But we have

$$(\mathfrak{A}', ..)(l, m, n)^2=(A, ..)(mz'-ny', ..)^2,$$
$$(\mathfrak{A}', ..)(l, m, n)(x, y, z)=(A, ..)(mz'-ny', ..)(yz'-y'z, ..),$$
$$(\mathfrak{B}'\mathfrak{C}'-\mathfrak{F}'^2, ..)(mz-ny, ..)(\lambda, \mu, \nu)$$
$$=[x'(mz-ny)+y'(nx-lz)+z'(ly-mx)](\lambda x'+\mu y'+\nu z')\,\mathrm{K}(a, ..)(x', y', z')^2,$$
$$(\mathfrak{B}'\mathfrak{C}'-\mathfrak{F}'^2, ..)(\lambda, \mu, \nu)^2=(\lambda x'+\mu y'+\nu z')^2\mathrm{K}(a, ..)(x', y', z')^2,$$

and thence

$$\frac{(\mathfrak{B}'\mathfrak{C}'-\mathfrak{F}'^2, ..)(mz-ny, ..)(\lambda, \mu, \nu)}{\sqrt{-(\mathfrak{B}'\mathfrak{C}'-\mathfrak{F}'^2, ..)(\lambda, \mu, \nu)^2}}=\begin{vmatrix} x, & y, & z \\ x', & y', & z' \\ l, & m, & n \end{vmatrix}\sqrt{-\mathrm{K}(a, ..)(x', y', z')^2},$$

whence we have

$$(A, ..\}(yz'-y'z, ..)^3=\frac{1}{(A, ..\}(mz'-ny')^3}\text{ Product of}$$

$$(A, ..\}(mz'-ny', ..\}(yz'-y'z, ..)\pm\begin{vmatrix} x, & y, & z \\ x', & y', & z' \\ l, & m, & n \end{vmatrix}\sqrt{-K(a, ..\}(x', y', z)^3};$$

And the identical equation

$$(a, ..\}(x, y, z)^3.(a, ..\}(x', y', z')^3-[(a, ..\}(x, y, z\}(x', y', z')]^3=(A, ..\}(yz'-y'z, ..)^3$$

now gives

$$(a, ..\}(x, y, z)^3=\text{ Quotient by }(a, ..\}(x', y', z')^3\text{ of }$$

I.
$$\left\{\begin{array}{l} [(a, ..\}(x, y, z\}(x', y', z')]^3 \\ +\text{ Quotient by }(A, ..\}(mz'-ny', ..)^3\text{ of Product} \\ (A, ..\}(mz'-ny', ..\}(yz'-y'z, ..)\pm\begin{vmatrix} x, & y, & z \\ x', & y', & z' \\ l, & m, & n \end{vmatrix}\sqrt{-K(a, ..\}(x', y', z')^3}, \end{array}\right.$$

where the Product part may also be written

$$\begin{array}{r} (a, ...\}(l, m, n\}(x', y', z').(a, ..\}(x, y, z\}(x', y', z') \\ -(a, ...\}(x', y', z')^3\quad .(a, ..\}(x, y, z\}(l, m, n) \\ \pm\sqrt{-K(a, ..\}(x', y', z')^3}\begin{vmatrix} x, & y, & z \\ x', & y', & z' \\ l, & m, & n \end{vmatrix}. \end{array}$$

19. Writing in the formula I.

$$\begin{pmatrix} a, & h, & g \\ h, & b, & f \\ g, & f, & c \end{pmatrix}\}(x', y', z')=(\xi, \eta, \zeta),$$

we have

$$(x', y', z')=\frac{1}{K}\begin{pmatrix} A, & H, & G \\ H, & B, & F \\ G, & F, & C \end{pmatrix}\}(\xi, \eta, \zeta),$$

and thence

$$K(a, ..\}(x', y', z')\quad =(A, ..\}(\xi, \eta, \zeta)^3$$
$$(a, ..\}(x, y, z\}(x', y', z')=\xi x+\eta y+\zeta z.$$

Assume

$$(l, m, n)=(\nu\eta'-\mu\zeta', \lambda\zeta'-\nu\xi', \mu\xi'-\lambda\eta'),$$

then from the foregoing values of (x', y', z')

$$mz'-ny'=\frac{1}{K}\{(\lambda\zeta'-\nu\xi')(G\xi'+F\eta'+C\zeta')-(\mu\xi'-\lambda\eta')(H\xi'+B\eta'+F\zeta')\}$$

$$=\frac{1}{K}\Big\{\lambda[\xi'(A\xi'+H\eta'+G\zeta')+\eta'(H\xi'+B\eta'+F\zeta')+\zeta'(G\xi'+F\eta'+C\zeta')]$$
$$-\lambda\xi'(A\xi'+H\eta'+G\zeta')$$
$$-\mu\xi'(H\xi'+B\eta'+F\zeta')$$
$$-\nu\xi'(G\xi'+F\eta'+C\zeta'),$$

that is

$$mz'-ny' =\frac{1}{K}\Big\{\lambda(A, ..\rangle\langle\xi', \eta', \zeta')^2-\xi(A, ..\rangle\langle\xi', \eta', \zeta'\rangle\langle\lambda, \mu, \nu)\Big\},$$

and similarly

$$nx'-lz' =\frac{1}{K}\Big\{\mu(A, ..\rangle\langle\xi', \eta', \zeta')^2-\eta'(A, ..\rangle\langle\xi', \eta', \zeta'\rangle\langle\lambda, \mu, \nu)\Big\},$$

$$ly'-mx' =\frac{1}{K}\Big\{\nu(A, ..\rangle\langle\xi', \eta', \zeta')^2-\zeta'(A, ..\rangle\langle\xi', \eta', \zeta'\rangle\langle\lambda, \mu, \nu)\Big\};$$

and thence

$$(A, H, G\rangle\langle mz'-ny', ..)=$$
$$\frac{1}{K}\Big\{(A, H, G\rangle\langle\lambda, \mu, \nu).(A, ..\rangle\langle\xi', \eta', \zeta')^2$$
$$-(A, H, G\rangle\langle\xi', \eta', \zeta').(A, ..\rangle\langle\xi', \eta', \zeta'\rangle\langle\lambda, \mu, \nu)\Big\}$$

with the like equations, writing H, B, F and G, F, C in the place of A, H, G successively: and we then have

$$(A, ..\rangle\langle mz'-ny', ..)^2$$
$$=\frac{1}{K}\Big\{(A, ..\rangle\langle\lambda, \mu, \nu\rangle\langle mz'-ny', ..).(A, ..\rangle\langle\xi', \eta', \zeta')^2$$
$$-(A, ..\rangle\langle\xi', \eta', \zeta'\rangle\langle mz'-ny', ..).(A, ..\rangle\langle\xi', \eta', \zeta'\rangle\langle\lambda, \mu, \nu)\Big\}.$$

But the foregoing values of $mz'-ny'$, $nx'-lz'$, $ly'-mx'$ give also

$$(A, ..\rangle\langle\lambda, \mu, \nu\rangle\langle mz'-ny', ..)$$
$$=\frac{1}{K}\Big\{(A, ..\rangle\langle\lambda, \mu, \nu)^2.(A, ..\rangle\langle\xi', \eta', \zeta')^2-[(A, ..\rangle\langle\lambda, \mu, \nu\rangle\langle\xi', \eta', \zeta')]^2\Big\}.$$

$$(A, ..\rangle\langle\xi', \eta', \zeta', \rangle\langle mz'-ny', ..)$$
$$=\frac{1}{K}\Big\{(A, ..\rangle\langle\lambda, \mu, \nu\rangle\langle\xi', \eta', \zeta').(A, ..\rangle\langle\xi', \eta', \zeta')^2-(A, ..\rangle\langle\xi', \eta', \zeta')^2.(A, ..\rangle\langle\lambda, \mu, \nu\rangle\langle\xi', \eta', \zeta')\Big\}=0.$$

So that

$$(A, ..\rangle\langle mz'-ny', ..)^2$$
$$=\frac{1}{K^2}(A, ..\rangle\langle\xi', \eta', \zeta')^2.\{(A, ..\rangle\langle\lambda, \mu, \nu)^2.(A, ..\rangle\langle\xi', \eta', \zeta')^2-[(A, ..\rangle\langle\lambda, \mu, \nu\rangle\langle\xi', \eta', \zeta')]^2\}$$
$$=\frac{1}{K}(A, ..\rangle\langle\xi', \eta', \zeta')^2.(a, ..\rangle\langle m'-\mu\zeta', ..)^2.$$

Similarly,

$$(A, ..)(mz'-ny', ..)(yz'-y'z, ..)$$
$$=\frac{1}{K}\Big\{(A, ..)(\lambda, \mu, \nu)(yz'-y'z, ..).(A, ..)(\xi, \eta, \zeta')^3$$
$$-(A, ..)(\xi, \eta, \zeta')(yz'-y'z, ..).(A, ..)(\xi, \eta, \zeta)(\lambda, \mu, \nu)\Big\}.$$

But

$$(A, ..)(\lambda, \mu, \nu)(yz'-y'z, ..)$$
$$= (A\lambda+H\mu+G\nu)(yz'-y'z)$$
$$+(H\lambda+B\mu+F\nu)(zx'-z'x)$$
$$+(G\lambda+F\mu+C\nu)(xy'-x'y)$$
$$= x[y'(G\lambda+F\mu+C\nu)-z'(H\lambda+B\mu+F\nu)]$$
$$+y[z'(A\lambda+H\mu+G\nu)-x'(G\lambda+F\mu+C\nu)]$$
$$+z[x'(H\lambda+B\mu+F\nu)-y'(A\lambda+H\mu+G\nu)],$$

which, substituting for x', y', z' their values

$$(x', y', z')=\frac{1}{K}\begin{pmatrix} A, & H, & G \\ H, & B, & F \\ G, & F, & C \end{pmatrix}(\xi, \eta, \zeta),$$

becomes

$$=\frac{1}{K}\Big\{ x[(BC-F^2)(m\eta-\mu\zeta')+(FG-CH)(\lambda\zeta'-\nu\xi)+(HF-BG)(\mu\xi-\lambda\eta')]$$
$$+y[(FG-CH)(m\eta-\mu\zeta')+(CA-G^2)(\lambda\zeta'-\nu\xi)+(GH-AF)(\mu\xi-\lambda\eta')]$$
$$+z(HF-BG)(m\eta-\mu\zeta')+(GH-AF)(\lambda\zeta'-\nu\xi)+(AB-H^2)(\mu\xi-\lambda\eta')\Big\},$$

which is

$$=(a, ..)(x, y, z)(m\eta-\mu\zeta', ..);$$

and by merely writing (ξ, η, ζ) in the place of (λ, μ, ν), we have

$$(A, ..)(\xi, \eta, \zeta')(yz'-y'z, ..)=0;$$

so that we find

$$(A, ..)(mz'-ny', ..)(yz'-y'z, ..)$$
$$=\frac{1}{K}(A, ..)(\xi, \eta, \zeta')^3.(a, ..)(x, y, z)(m\eta-\mu\zeta', \lambda\zeta'-\nu\xi, \mu\xi-\lambda\eta').$$

Now, writing the formula I. in the form

$$(a, ..)(x, y, z)^3=\text{Quotient by } K(a, ..)(x', y', z')^3 \text{ of}$$
$$\Big\{\begin{array}{l} K[(a, ..)(x, y, z)(x', y', z')]^3 \\ +\text{Quotient by } K(A, ..)(mz'-ny', ..)^3 \text{ of} \\ K^3\{[(A, ..)(mz'-ny', ..)(yz'-y'z, ..)]^3+\begin{vmatrix} x, & y, & z \\ x', & y', & z' \\ l, & m, & n \end{vmatrix}^3 K(a, ..)(x, y, z)^3\}, \end{array}$$

the right-hand side is

$$=\text{Quotient by } (A, ..\chi(\xi', \eta', \zeta')^3 \text{ of}$$

$$\left\{\begin{array}{l} K(\xi' x+\eta' y+\zeta' z)^3 \\ +\text{Quotient by } (a, ..\chi(m'-\mu\zeta', ..)^3 (A, ..\chi(\xi', \eta', \zeta')^3 \text{ of} \\ \{[(a, ..\chi(m'-\mu\zeta', ..\chi(x, y, z)).(A, ..\chi(\xi', \eta', \zeta')^3]^2+\Pi^2(A, ..\chi(\xi', \eta', \zeta')^3\}, \end{array}\right.$$

where

$$\Pi=K\begin{vmatrix} x, & y, & z \\ x', & y', & z' \\ l, & m, & n \end{vmatrix},$$

or, what is the same thing,

$$\Pi=\begin{vmatrix} x, & y, & z \\ Kx', & Ky', & Kz' \\ l, & m, & n \end{vmatrix}=\begin{vmatrix} x & y & z \\ A\xi'+H\eta'+G\zeta', & H\xi'+B\eta'+F\zeta', & G\xi'+F\eta'+C\zeta' \\ m'-\mu\zeta', & \lambda\zeta'-n\xi', & \mu\xi'-\lambda\eta' \end{vmatrix};$$

More simply, the right-hand side is

$$=\text{Quotient by } (A, ..\chi(\xi', \eta', \zeta')^3 \text{ of}$$

$$\left\{\begin{array}{l} K(\xi' x+\eta' y+\zeta' z)^3 \\ +\text{Quotient by } (a, ..\chi(m'-\mu\zeta', ..)^3 \text{ of} \\ \{[(a, ..\chi(m'-\mu\zeta', ..\chi(x, y, z)]^2(A, ..\chi(\xi', \eta', \zeta')^3+\Pi^2\}; \end{array}\right.$$

Or restoring the left-hand side, and resolving into its linear factors the function in $\{\}$, we have

$$(a, ..\chi(x, y, z)^3=\text{Quotient by } (A, ..\chi(\xi', \eta', \zeta')^3 \text{ of}$$

II.

$$\left\{\begin{array}{l} K(\xi' x+\eta' y+\zeta' z)^3 \\ +\text{Quotient by } (a, ..\chi(m'-\mu\zeta', ..)^3 \text{ of Product} \\ \Pi\pm\sqrt{-(A, ..\chi(\xi', \eta', \zeta')^3}(a, ..\chi(m'-\mu\zeta', ..\chi(x, y, z), \end{array}\right.$$

where Π has the value given above, which may also be written

$$\Pi=\ (A, ..\chi(\xi', \eta', \zeta'\chi(\lambda, \mu, \nu)(\xi' x+\eta' y+\zeta' z)$$
$$-(A, ..\chi(\xi', \eta', \zeta')^3(\lambda x+\mu y+\nu z).$$

20. We deduce at once the inverse or reciprocal formulæ

$$(A, ..\chi(\xi, \eta, \zeta)^3=\text{Quotient by } (A, ..\chi(\xi', \eta', \zeta')^3 \text{ of}$$

III.

$$\left\{\begin{array}{l} [(A, ..\chi(\xi, \eta, \zeta\chi(\xi', \eta', \zeta')]^3 \\ +\text{Quotient by } (a, ..\chi(m'-\mu\zeta', ..)^3 \text{ of K into Product} \\ (a, ..\chi(m'-\mu\zeta', ..\chi(n\zeta'-\nu\zeta', ..)\pm\sqrt{-(A, ..\chi(\xi', \eta', \zeta')^3}\begin{vmatrix} \xi, & \eta, & \zeta \\ \xi', & \eta', & \zeta' \\ \lambda, & \mu, & \nu \end{vmatrix}, \end{array}\right.$$

where the Product part may also be written

$$\text{Product}\left[\frac{1}{K}(A,..\chi\xi,\eta',\zeta'\chi\lambda,\mu,\nu).(A,..\chi\xi,\eta',\zeta'\chi\xi,\eta,\zeta)\right.$$
$$-\frac{1}{K}(A,..\chi\xi,\eta',\zeta')^3\quad.(A,..\chi\lambda,\mu,\nu\chi\xi,\eta,\zeta)$$
$$\left.\pm\sqrt{-(A,..\chi\xi,\eta',\zeta')^3}\begin{vmatrix}\xi, & \eta, & \zeta\\ \xi', & \eta', & \zeta'\\ \lambda, & \mu, & \nu\end{vmatrix}\right].$$

21. And also

$$(A,..\chi\xi,\eta,\zeta)^3 = \text{Quotient by } (a,..\chi x',y',z')^3 \text{ of}$$

IV.
$$\begin{cases}K(\xi x'+\eta y'+\zeta z')^3\\ +\text{Quotient by } K(A,..\chi ny'-mz',..)^3 \text{ of Product}\\ K\Phi\pm\sqrt{-K(a,..\chi x',y',z')^3}(A,..\chi ny'-mz',..\chi\xi,\eta,\zeta),\end{cases}$$

where

$$\Phi=\begin{vmatrix}\xi & \eta & \zeta\\ ax'+hy'+gz', & hx'+by'+fz', & gx'+fy'+cz'\\ ny'-mz', & lz'-nx', & mx'-ly'\end{vmatrix},$$

which may also be written

$$=(a,..\chi x',y',z'\chi l,m,n)(x'\xi+y'\eta+z'\zeta)$$
$$-(a,..\chi x',y',z')^3\quad.\quad(l\xi+m\eta+n\zeta).$$

22. The geometrical signification is obvious. The formulæ I. and II. each of them show that the equation

$$(a,..\chi x,y,z)^3=0$$

of the conic may be written in the form

$$W^2+\frac{1}{M}QR=0,$$

where $Q=0$, $R=0$ are any two tangents of the conic, and $W=0$ is the line joining the points of contact, or chord of contact corresponding to the two tangents; viz., in the formula I. we have

$$W=(a,..\chi x',y',z'\chi x,y,z),$$

$$\left.\begin{matrix}Q\\ R\end{matrix}\right\}=(A,..\chi mz'-ny',..\chi yz'-y'z,..)\pm\sqrt{-K(a,..\chi x,y,z)^3}\begin{vmatrix}x, & y, & z\\ x', & y', & z'\\ l, & m, & n\end{vmatrix}$$

(or for a different form of Q, R see the formula). The quantities (x', y', z') are the coordinates of the point of intersection of the two tangents, or pole of the chord of

contact: (l, m, n) are supernumerary arbitrary quantities, the values whereof do not affect the result*. And in the formula II. we have

$$\left.\begin{matrix} W \\ Q \\ R \end{matrix}\right\} = \Pi \pm \sqrt{-(A, ..)(\xi', \eta', \zeta')^2}\,(a, ..)(\eta'\zeta - \mu\zeta', ..)(x, y, z)$$

(for the value of Π see the formula). The quantities (ξ', η', ζ') are the line-coordinates of the chord of contact (viz. the point-equation of this line is $\xi'x+\eta'y+\zeta'z=0$); (λ, μ, ν) are supernumerary arbitrary quantities.

23. In the like manner the formulæ III. and IV. each of them show that the line-equation

$$(A, ..)(\xi, \eta, \zeta)^2 = 0$$

of the conic may be written in the form

$$W^2 + \frac{1}{M}QR = 0,$$

where $Q=0$, $R=0$ are any two ineunts of the conic, and $W=0$ is the point of intersection of the corresponding tangents; viz. in the formula III. we have

$$W = (A, ..)(\xi', \eta', \zeta')(\xi, \eta, \zeta),$$

$$\left.\begin{matrix} Q \\ R \end{matrix}\right\} = (a, ..)(\eta'\zeta - \mu\zeta', ..) \pm \sqrt{-(A, ..)(\xi', \eta', \zeta')^2}\,\begin{vmatrix} \xi, & \eta, & \zeta \\ \xi', & \eta', & \zeta' \\ \lambda, & \mu, & \nu \end{vmatrix}$$

(for another form of Q, R see the formula).

The quantities ξ', η', ζ' are the line-coordinates of the line through the two ineunts, or chord of contact; (λ, μ, ν) are supernumerary arbitrary quantities; and so in the formula IV. we have

$$\left.\begin{matrix} W \\ Q \\ R \end{matrix}\right\} = K\Phi \pm \sqrt{-K(a, ..)(x', y', z')^2}\,(A, ..)(ny' - mz', ..)(\xi, \eta, \zeta)$$

(for the value of Φ see the formula), where x', y', z' are the point-coordinates of the intersection of tangents at the two ineunts, or pole of the chord of contact; (l, m, n) are supernumerary arbitrary quantities.

24. We may, instead of the supernumerary arbitrary quantities (l, m, n) of the formula I., introduce the quantities (λ, μ, ν), where

$$(l, m, n) = \frac{1}{K}\begin{pmatrix} A, & H, & G \\ H, & B, & F \\ G, & F, & C \end{pmatrix}(\lambda, \mu, \nu).$$

* In a different point of view, viz. if we consider the formula I. as a transformation of the function $(a, ..)(x, y, z)^2$, then (x', y', z') and (l, m, n) would be each of them supernumerary arbitrary quantities: and so in the other like cases.

This gives

$$\begin{aligned}
&(A, H, G)(mx'-ny', ..)\\
&\quad = A(mx'-ny') + H(nx'-lz') + G(ly' - mx')\\
&\quad = x'(Hn - Gm) + y'(Gl - An) + z'(Am - Hl)\\
&\quad = \frac{1}{K}\cdot\ x'[H(G\lambda + F\mu + C\nu) - G(H\lambda + B\mu + F\nu)]\\
&\qquad\quad + y'[G(A\lambda + H\mu + G\nu) - A(G\lambda + F\mu + C\nu)]\\
&\qquad\quad + z'[A(H\lambda + B\mu + F\nu) - H(H\lambda + B\mu + F\nu)]\\
&\quad = \qquad x'(g\mu - h\nu) + y'(f\mu - b\nu) + z'(c\mu - f\nu)\\
&\quad = \qquad \mu(gx' + fy' + cz') - \nu(hx' + by' + fz').
\end{aligned}$$

We have thus the system

$$\begin{aligned}
&(A, H, G)(mx'-ny', ..) = \mu(gx' + fy' + cz') - \nu(hx' + by' + fz'),\\
&(H, B, F)(mx'-ny', ..) = \nu(ax' + hy' + gz') - \lambda(gx' + fy' + cz'),\\
&(G, F, C)(mx'-ny', ..) = \lambda(hx' + by' + fz') - \mu(ax' + hy' + gz'),
\end{aligned}$$

and thence

$$\begin{aligned}
&(A, ..)(mx'-ny', ..)(yz'-y'z, ..)\\
&\quad = -\begin{vmatrix} yz'-y'z & , & zx'-z'x & , & xy'-x'y \\ ax'+hy'+gz', & & hx'+by'+fz', & & gx'+fy'+cz' \\ \lambda & , & \mu & , & \nu \end{vmatrix};
\end{aligned}$$

or observing that the term in λ is

$$-(zx'-z'x)(gx'+fy'+cz') + (xy'-x'y)(hx'+by'+fz'),$$

which is

$$\begin{aligned}
&= x(x'(ax'+hy'+gz') + y'(hx'+fy'+fz') + z'(gx'+fy'+cz'))\\
&\quad - x.x'(ax'+hy'+gz')\\
&\quad - y.x'(hx'+by'+fz')\\
&\quad - z.x'(gx'+fy'+cz')\\
&= -x'(a, ..)(x, y, z)(x', y', z') + x(a, ..)(x', y', z')^2,
\end{aligned}$$

with similar expressions for the terms in μ, ν, we have

$$\begin{aligned}
&(A, ..)(mx'-ny', ..)(yz'-y'z, ..)\\
&\quad = -(\lambda x' + \mu y' + \nu z').(a, ..)(x, y, z)(x', y', z') + (\lambda x + \mu y + \nu z).(a, ..)(x', y', z')^2;
\end{aligned}$$

and so also

$$\begin{aligned}
&(A, ..)(mx'-ny', ..)^2\\
&\quad = -(\lambda x' + \mu y' + \nu z').(a, ..)(l, m, n)(x', y', z') + (\lambda l + \mu m + \nu n).(a, ..)(x', y', z')^2,
\end{aligned}$$

where

$$\begin{aligned}
&(a, ..)(l, m, n)(x', y', z') = \lambda x' + \mu y' + \nu z',\\
&\lambda l + \mu m + \nu n \qquad\qquad = \frac{1}{K}(A, ..)(\lambda, \mu, \nu)^2,
\end{aligned}$$

so that

$$(A, ..\}mz'-ny', ..)^3 = -(\lambda x'+\mu y'+\nu z')^3 + \frac{1}{K}(A, ..\}\lambda, \mu, \nu)^3.(a, ..\}x', y', z')^3.$$

Moreover,

$$\begin{vmatrix} x, & y, & z \\ x', & y', & z' \\ l, & m, & n \end{vmatrix} = \frac{1}{K}\left\{(A\lambda+H\mu+G\nu)(yz'-y'z)+(H\lambda+B\mu+F\nu)(zx'-z'x)+(G\lambda+F\mu+C\nu)(xy'-x'y)\right\},$$

which is

$$= \frac{1}{K}(A, ..\}\lambda, \mu, \nu\}yz'-y'z, ..);$$

and hence instead of the formula I. we have

I. (bis)
$$(a, ..\}x, y, z)^3 = \text{Quotient by } (a, ..\}x', y', z')^3 \text{ of}$$
$$\left\{\begin{array}{l} \overline{[(a, ..\}x, y, z\}x', y', z')]^3} \\ +\text{Quotient by } +(A, ..\}\lambda, \mu, \nu)^3(a, ..\}x', y', z')^3 - K(\lambda x'+\mu y'+\nu z')^3 \text{ of K Product} \\ \left\{\begin{array}{l}(\lambda x'+\mu y'+\nu z').(a, ..\}x, y, z\}x', y', z') - (\lambda x+\mu y+\nu z).(a, ..\}x', y', z')^3 \\ \pm\frac{1}{K}\sqrt{-K(a, ..\}x', y', z')^3}(A, ..\}\lambda, \mu, \nu\}yz'-y'z, ..). \end{array}\right\} \end{array}\right\}$$

25. If, in like manner, in the formula II. we introduce, instead of (λ, μ, ν), the new quantities (l, m, n), where

$$(\lambda, \mu, \nu) = \begin{pmatrix} a, & h, & g \\ h, & b, & f \\ g, & f, & c \end{vmatrix}\}l, m, n),$$

or, what is the same thing,

$$(l, m, n) = \frac{1}{K}\begin{pmatrix} A, & H, & G \\ H, & B, & F \\ G, & F, & C \end{vmatrix}\}\lambda, \mu, \nu),$$

then we have

$$(a, h, g\}m'-\mu\zeta', ..) = n(H\xi'+B\eta'+F\zeta') - m(G\xi'+F\eta'+C\zeta'),$$
$$(h, b, f\}m'-\mu\zeta', ..) = l(G\xi'+F\eta'+C\zeta') - n(A\xi'+H\eta'+G\zeta'),$$
$$(g, f, c\}m'-\mu\zeta', ..) = m(A\xi'+H\eta'+G\zeta') - l(H\xi'+B\eta'+F\zeta');$$

and thence

$$(a, ..\}m'-u\zeta', ..\}x, y, z) = \begin{vmatrix} x, & y, & z \\ A\xi'+H\eta'+G\zeta', & H\xi'+B\eta'+F\zeta', & G\xi'+F\eta'+C\zeta' \\ l, & m, & n \end{vmatrix}$$
$$= (A, ..\}mz-ny, ..\}\xi', \eta', \zeta'),$$

$$(a, ..\}m'-\mu\zeta', ..)^3 = \frac{1}{K}\left\{(A, ..\}\lambda, \mu, \nu)^3.(A, ..\}\xi', \eta', \zeta')^3 - [(A, ..\}\lambda, \mu, \nu\}\xi', \eta', \zeta')]^3\right\}$$
$$= (a, ..\}l, m, n)^3.(A, ..\}\xi', \eta', \zeta')^3 - K(l\xi'+m\eta'+n\zeta')^3;$$

$$V=\begin{vmatrix} x & , & y & , & z \\ A\xi+H\eta+G\zeta, & & H\xi+B\eta+F\zeta, & & G\xi+F\eta+C\zeta \\ \nu\eta'-\mu\zeta' & , & \lambda\zeta'-\nu\xi' & , & \mu\xi'-\lambda\eta' \end{vmatrix}$$

$$=(\nu\eta'-\mu\zeta').y(G\xi+F\eta+C\zeta')-z(H\xi'+B\eta'+F\zeta')$$
$$(\lambda\zeta'-\nu\xi').z(A\xi'+H\eta'+G\zeta')-x(G\xi+F\eta'+C\zeta')$$
$$(\mu\xi'-\lambda\eta').x(H\xi'+B\eta'+F\zeta')-y(A\xi'+H\eta'+G\zeta')$$

$$=\lambda\{(\xi x+\eta' y+\zeta' z)(A\xi'+H\eta'+G\zeta')-x(A,..\chi(\xi',\eta',\zeta')^2\}$$
$$+\mu\{(\xi x+\eta' y+\zeta' z)(H\xi'+B\eta'+F\zeta')-y(A,..\chi(\xi',\eta',\zeta')^2\}$$
$$+\nu\{(\xi x+\eta' y+\zeta' z)(G\xi'+F\eta'+C\zeta')-z(A,..\chi(\xi',\eta',\zeta')^2\}$$

$$=(\xi' x+\eta' y+\zeta' z).(A,..\chi(\lambda,\mu,\nu)(\xi',\eta',\zeta')-(\lambda x+\mu y+\nu z).(A,..\chi(\xi',\eta',\zeta')^2$$

$$=K(l\xi'+m\eta'+n\zeta').(\xi x+\eta' y+\zeta' z)-(a,..\chi(l,m,n)(x,y,z).(A,..\chi(\xi',\eta',\zeta')^2;$$

and the formula II. thus becomes

$$(a,..\chi(x,y,z)^2=\text{Quotient by } (A,..\chi(\xi',\eta',\zeta')^2 \text{ of}$$

II. (bis)
$$\begin{cases} K(\xi' x+\eta' y+\zeta' z)^2 \\ +\text{Quotient by } (a,..\chi(l,m,n)^2.(A,..\chi(\xi',\eta',\zeta')^2-K(l\xi'+m\eta'+n\zeta')^2 \text{ of Product} \\ \begin{cases} K(l\xi'+m\eta'+n\zeta').(\xi' x+\eta' y+\zeta' z)-(a,..\chi(l,m,n)(x,y,z).(A,..\chi(\xi',\eta',\zeta')^2 \\ \pm\sqrt{-(A,..\chi(\xi',\eta',\zeta')^2(A,..\chi(mz-ny,..\chi(\xi',\eta',\zeta'). \end{cases} \end{cases}$$

26. And from these we at once deduce the inverse or reciprocal formulæ

$$(A,..\chi(\xi,\eta,\zeta)^2=\text{Quotient by } (A,..\chi(\xi',\eta',\zeta')^2 \text{ of}$$

III. (bis)
$$\begin{cases} [(A,..\chi(\xi,\eta,\zeta)(\xi',\eta',\zeta')]^2 \\ +\text{Quotient by } (a,..\chi(l,m,n)^2.(A,..\chi(\xi',\eta',\zeta')^2-K(l\xi'+m\eta'+n\zeta')^2 \text{ of K into Product} \\ \begin{cases} (l\xi'+m\eta'+n\zeta')(A,..\chi(\xi,\eta,\zeta)(\xi',\eta',\zeta')-(l\xi+m\eta+n\zeta).(A,..\chi(\xi,\eta,\zeta')^2 \\ \pm\sqrt{-(A,..\chi(\xi',\eta',\zeta')^2(a,..\chi(l,m,n)(\eta\zeta'-\eta'\zeta,..), \end{cases} \end{cases}$$

27. And

$$(A,..\chi(\xi,\eta,\zeta)^2=\text{Quotient by } (a,..\chi(x',y',z')^2 \text{ of}$$

IV. (bis)
$$\begin{cases} K(x'\xi+y'\eta+z'\zeta)^2 \\ +\text{Quotient by } (A,..\chi(\lambda,\mu,\nu)^2.(a,..\chi(x',y',z')^2-K(\lambda x'+\mu y'+\nu z')^2 \text{ of Product} \\ \begin{cases} K(\lambda x'+\mu y'+\nu z').(x'\xi+y'\eta+z'\zeta)-(A,..\chi(\xi,\eta,\zeta)(l,m,n).(a,..\chi(x',y',z')^2 \\ \pm\sqrt{-K(a,..\chi(x',y',z')^2(a,..\chi(x',y',z')(\mu\zeta-\nu\eta,..), \end{cases} \end{cases}$$

which four formulæ have the same geometrical significations with the original four formulæ to which they correspond respectively.

28. The eight formulæ become all of them the same or very similar for the quadric form $(a, \ldots)(x, y, z)^2 = x^2 + y^2 + z^2$, which of course implies $(A, \ldots)(\xi, \eta, \zeta)^2 = \xi^2 + \eta^2 + \zeta^2$. Thus selecting any one of them at pleasure, *e. g.* the formula II. (bis), this becomes

$$\begin{aligned}
&\{(x^2+y^2+z^2)(\xi^2+\eta^2+\zeta^2)-(\xi x+\eta y+\zeta' z)^2\}\\
&\times\{(l^2+m^2+n^2)(\xi^2+\eta^2+\zeta^2)-(l\xi'+m\eta'+n\zeta')^2\}\\
&=\{(l\xi'+m\eta'+n\zeta')(x\xi'+m\eta'+n\zeta')-(lx+my+nz)(\xi^2+\eta^2+\zeta^2)\}^2\\
&+(\xi^2+\eta^2+\zeta^2)\begin{vmatrix} \xi', & \eta', & \zeta' \\ x, & y, & z \\ l, & m, & n \end{vmatrix}^2,
\end{aligned}$$

where the terms independent of $\xi^2+\eta^2+\zeta^2$ destroy each other. Omitting these terms, and dividing by $\xi^2+\eta^2+\zeta^2$, the resulting equation is found to be

$$\begin{vmatrix} \xi', & \eta', & \zeta' \\ x, & y, & z \\ l, & m, & n \end{vmatrix}^2 = \begin{vmatrix} \xi^2+ & \eta^2+ & \zeta^2, & \xi x+\eta y+\zeta' z, & \xi l+\eta m+\zeta n \\ x\xi'+ & y\eta'+ & z\zeta', & x^2+ & y^2+ & z^2, & xl+ym+zn \\ l\xi'+ & m\eta'+ & n\zeta', & lx+my+nz, & l^2+ & m^2+ & n^2, \end{vmatrix},$$

which is a well-known identical equation.

Article Nos. 29 to 33, relating to a single conic in connexion with an ineunt or a tangent of a conic of double contact.

29. The formulæ assume a very simple form when the point of intersection of the two tangents, or the line of junction of the two ineunts of the conic, is an ineunt or a tangent of a conic having double contact with the first-mentioned conic. Thus, if to the conic

$$(a, \ldots)(x, y, z)^2 = 0$$

tangents are drawn from a point (x', y', z') of the conic

$$(a, \ldots)(x, y, z)^2 + (\xi' x + \eta' y + \zeta' z)^2 = 0,$$

then we have

$$(a, \ldots)(x', y', z')^2 = -(\xi' x' + \eta' y' + \zeta' z')^2;$$

and using the form I. (bis), and putting therein (ξ', η', ζ') in the place of the arbitrary quantities (λ, μ, ν), the equation of the tangent divides out by $\xi' x' + \eta' y' + \zeta' z'$, and omitting this factor it becomes

$$\begin{aligned}
&(a, \ldots)(x', y', z')(x, y, z) + (\xi' x' + \eta' y' + \zeta' z')(\xi' x + \eta' y + \zeta' z)\\
&\pm\frac{1}{\sqrt{R}}(A, \ldots)(\xi', \eta', \zeta')(yz'-y'z,\ zx'-z'x,\ xy'-x'y) = 0,
\end{aligned}$$

which is of the form

$$\begin{vmatrix} \alpha, & \beta, & \gamma \\ \alpha', & \beta', & \gamma' \\ \alpha'', & \beta'', & \gamma'' \end{vmatrix}(x', y', z')(x, y, z) = 0,$$

where the matrix

$$\left\{\begin{vmatrix} \alpha, & \beta, & \gamma \\ \alpha', & \beta', & \gamma \\ \alpha'', & \beta'', & \gamma'' \end{vmatrix}\right\} \text{ is } =$$

$$a+\xi^2, \quad h+\xi\eta'+\frac{1}{\sqrt{K}}(G\xi'+F\eta'+C\zeta'), \quad g+\xi\zeta'-\frac{1}{\sqrt{K}}(H\xi'+B\eta'+F\zeta')$$

$$h+\xi\eta'-\frac{1}{\sqrt{K}}(G\xi'+F\eta'+C\zeta'), \quad b+\eta^2, \quad f+\eta'\zeta'+\frac{1}{\sqrt{K}}(A\xi'+H\eta'+G\zeta')$$

$$g+\xi\zeta'+\frac{1}{\sqrt{K}}(H\xi'+B\eta'+F\zeta'), \quad f+\eta'\zeta'-\frac{1}{\sqrt{K}}(A\xi'+H\eta'+G\zeta'), \quad c+\zeta^2.$$

30. But instead of further developing these formulæ, I prefer to consider the formulæ which give the points of contact of the tangents in question, viz. the ineunts of the conic $(a, \ldots)(x, y, z)^2=0$, or the tangents through the point (x', y', z') of the conic $(a, \ldots)(x, y, z)^2+(\xi x+\eta' y+\zeta' z)^2=0$.

We have as before

$$(a, \ldots)(x', y', z')^2=-(\xi x'+\eta' y'+\zeta' z')^2,$$

and using the formula IV.(bis) and writing therein (ξ', η', ζ') in the place of the arbitrary quantities (λ, μ, ν), the equation contains the factor $\xi x'+\eta' y'+\zeta' z'$, and dividing by this factor, and by K, the line-equation of the ineunt is

$$x'\xi+y'\eta+z'\zeta+\frac{1}{K}(x'\xi'+y'\eta'+z'\zeta')(A, \ldots)(\xi', \eta', \zeta')(\xi, \eta, \zeta)$$

$$\pm\frac{1}{\sqrt{K}}(a, \ldots)(x', y', z')(\eta\zeta'-\eta'\zeta, \ldots)=0.$$

Selecting the positive sign, the coordinates of the corresponding ineunt are

$$x'+\frac{1}{K}(x'\xi'+y'\eta'+z'\zeta')(A\xi'+H\eta'+G\zeta')+\frac{1}{\sqrt{K}}\left\{\eta'(gx'+fy'+cz')-\zeta'(hx'+by'+fz')\right\},$$

$$y'+\frac{1}{K}(x'\xi'+y'\eta'+z'\zeta')(H\xi'+B\eta'+F\zeta')+\frac{1}{\sqrt{K}}\left\{\zeta'(ax'+hy'+gz')-\xi'(gx'+fy'+cz')\right\},$$

$$z'+\frac{1}{K}(x'\xi'+y'\eta'+z'\zeta')(G\xi'+F\eta'+C\zeta')+\frac{1}{\sqrt{K}}\left\{\xi'(hx'+by'+fz')-\eta'(ax'+hy'+gz')\right\};$$

and taking (X, Y, Z) for the coordinates of the ineunt in question, and putting for shortness

$$\alpha=1-\frac{1}{\sqrt{K}}(g\eta'-h\zeta'), \quad \beta=-\frac{1}{\sqrt{K}}(f\eta'-b\zeta'), \quad \gamma=-\frac{1}{\sqrt{K}}(c\eta'-f\zeta'),$$

$$\alpha'=-\frac{1}{\sqrt{K}}(a\zeta'-g\xi'), \quad \beta'=1-\frac{1}{\sqrt{K}}(h\zeta'-f\xi'), \quad \gamma'=-\frac{1}{\sqrt{K}}(g\zeta'-c\xi'),$$

$$\alpha''=-\frac{1}{\sqrt{K}}(h\xi'-a\eta'), \quad \beta''=-\frac{1}{\sqrt{K}}(b\xi'-h\eta'), \quad \gamma''=1-\frac{1}{\sqrt{K}}(f\xi'-g\eta'),$$

we may write

$$(1+P)X=(2-\alpha)x' \quad -\beta y' \quad -\gamma z' \quad +\frac{1}{K}(A\xi'+H\eta'+G\zeta')(\xi'x'+\eta'y'+\zeta'z'),$$

$$(1+P)Y= \quad -\alpha' x' \quad +(2-\beta')y' \quad -\gamma' z' \quad +\frac{1}{K}(H\xi'+B\eta'+F\zeta')(\xi'x'+\eta'y'+\zeta'z'),$$

$$(1+P)Z= \quad \alpha'' x'' \quad -\beta'' y' \quad +(2-\gamma'')z' \quad +\frac{1}{K}(G\xi'+F\eta'+C\zeta')(\xi'x'+\eta'y'+\zeta'z'),$$

where P, which is arbitrary, may be put

$$=\frac{1}{K}(A, \ldots)(\xi', \eta', \zeta')^2.$$

31. These equations then give

$$(x', y', z')=\begin{pmatrix} \alpha, & \beta, & \gamma \\ \alpha', & \beta', & \gamma' \\ \alpha'', & \beta'', & \gamma'' \end{pmatrix}(X, Y, Z),$$

which can be verified without difficulty by reversing the process; and we have thus the coordinates (X, Y, Z) in terms of (x', y', z'), and reciprocally.

32. If (X_1, Y_1, Z_1) are the coordinates of the other ineunt, we have, it is clear,

$$(x', y', z')=\begin{pmatrix} 2-\alpha, & -\beta, & -\gamma \\ -\alpha', & 2-\beta', & -\gamma' \\ -\alpha'', & -\beta'', & 2-\gamma'' \end{pmatrix}(X_1, Y_1, Z_1);$$

or substituting for (x', y', z') their values in terms of (X, Y, Z),

$$(2X_1, 2Y_1, 2Z_1)=\begin{pmatrix} \alpha, & \beta, & \gamma \\ \alpha', & \beta', & \gamma' \\ \alpha'', & \beta'', & \gamma'' \end{pmatrix}(X+X_1, Y+Y_1, Z+Z_1),$$

so that $(X+X_1, Y+Y_1, Z+Z_1)$ are the same linear functions of $2X_1$, $2Y_1$, $2Z_1$ that (X, Y, Z) are of (x', y', z'); that is, we have

$$\tfrac{1}{2}(1+P)(X+X_1)=(2-\alpha)X_1- \quad \beta Y_1- \quad \gamma Z_1+\frac{1}{K}(A\xi'+H\eta'+G\zeta')(\xi'x'+\eta'y'+\zeta'z'),$$

$$\tfrac{1}{2}(1+P)(X+X_1)= \quad -\alpha' X_1+(2-\beta')Y_1- \quad \gamma' Z_1+\frac{1}{K}(H\xi'+B\eta'+F\zeta')(\xi'x'+\eta'y'+\zeta'z'),$$

$$\tfrac{1}{2}(1+P)(X+X_1)= \quad -\alpha'' X_1- \quad \beta'' Y_1+(2-\gamma'')Z_1+\frac{1}{K}(G\xi'+F\eta'+C\zeta')(\xi'x'+\eta'y'+\zeta'z'),$$

which equations may be written

$$(1+P)(X, Y, Z)=\begin{pmatrix} a, & b, & c \\ a', & b', & c' \\ a'', & b'', & c'' \end{pmatrix}(X_1, Y_1, Z_1),$$

where the values of the coefficients are

$$1-\frac{2}{\sqrt{K}}(g\eta'-h\zeta')+\frac{1}{K}(A\xi^2-B\eta^2-2F\eta\zeta-C\zeta^2),\quad -\frac{2}{\sqrt{K}}(f\eta'-h\zeta')+\frac{2}{K}\eta'(A\xi+H\eta+G\zeta)\quad ,\ -\frac{2}{\sqrt{K}}(c\eta'-f\zeta')+\frac{2}{K}\zeta'(A\xi+H\eta+G\zeta)$$

$$-\frac{2}{\sqrt{K}}(a\zeta'-g\xi')+\frac{2}{K}\xi'(H\xi+B\eta+F\zeta)\quad ,1-\frac{2}{\sqrt{K}}(h\zeta'-f\eta')+\frac{1}{K}(B\eta^2-C\zeta^2-2G\zeta\xi-A\xi^2),\quad -\frac{2}{\sqrt{K}}(g\zeta'-c\xi')+\frac{2}{K}\zeta'(H\xi+B\eta+F\zeta)$$

$$-\frac{2}{\sqrt{K}}(h\xi'-a\eta')+\frac{2}{K}\xi'(G\xi+F\eta+C\zeta)\quad ,\ -\frac{2}{\sqrt{K}}(h\xi'-b\eta')+\frac{2}{K}\eta'(G\xi+F\eta+C\zeta)\quad ,1-\frac{2}{\sqrt{K}}(f\xi'-g\eta')+\frac{1}{K}(C\zeta^2-A\xi^2-2H\xi\eta-B\eta^2),$$

and considering (X, Y, Z) and (X_1, Y_1, Z_1) as quantities connected by the foregoing linear relations, we have identically

$$(a, ..\chi X, Y, Z)^2=(a, ..\chi X_1, Y_1, Z_1)^2.$$

So that the investigation leads to the automorphic transformation of the quadric function, a transformation first effected by M. HERMITE*.

33. It is to be remarked that the foregoing formulæ show that (x', y', z') being the coordinates of a point on the conic $(a, ..\chi x, y, z)^2+(\xi x+\eta y+\zeta z)^2=0$, from which point tangents are drawn to the conic $(a, ..\chi x, y, z)^2=0$, then the coordinates (x', y', z') enter *linearly* into the equations of the tangents, the ineunts (or points of contact), and the polar. And it may be added that the equation of the conic enveloped by the polar (that is, the polar conic of $(a, ..\chi x, y, z)^2+(\xi x+\eta y+\zeta z)^2=0$) has for its equation

$$\{K+(A, ..\chi\xi, \eta, \zeta)^2\}(a, ..\chi x, y, z)^2-K(\xi x+\eta y+\zeta z)^2=0.$$

and that the coordinates of the point of contact of the polar with this conic are

$$x'+\frac{1}{K}(A\xi+H\eta+G\zeta)(\xi x'+\eta y'+\zeta z'),$$

$$y'+\frac{1}{K}(H\xi+B\eta+F\zeta)(\xi x'+\eta y'+\zeta z'),$$

$$z'+\frac{1}{K}(G\xi+F\eta+C\zeta)(\xi x'+\eta y'+\zeta z');$$

so that (x', y', z') also enter linearly into the expressions for the coordinates of the last-mentioned point.

Article Nos. 34 to 37, relating to two conics.

34. Considering now the two conics

$$U=(a, b, c, f, g, h\chi x, y, z)^2=0,$$

$$U=(a', b', c', f', g', h'\chi x, y, z)^2=0;$$

Suppose that the conic

$$\theta U+\theta' U'=(\theta a+\theta' a', ..\chi x, y, z)^2=0$$

represents a pair of lines.

* See my "Memoir on the Automorphic Transformation of a Bipartite Quadric Function," Phil. Trans. vol. cxlviii. (1858) pp. 39–46.

The condition for this is

$$\text{Disct. } (\theta a+\theta' a', \ldots)(x, y, z)^2=0,$$

which is

$$(\mathfrak{A}, \mathfrak{B}, \mathfrak{C}, \mathfrak{D})(\theta, \theta')^3=0,$$

where

$$\mathfrak{A}=K,$$
$$\mathfrak{B}=Aa'+Bb'+Cc'+2Ff'+2Gg'+2Hh',$$
$$\mathfrak{C}=A'a+B'b+C'c+2F'f+2G'g+2H'h,$$
$$\mathfrak{D}=K'$$

(the significations of K', A', B', C', F', G', H' being of course analogous to those of K, A, B, C, F, G, H). The three roots $\theta : \theta'$ correspond, it is clear, to the three pairs of lines which can be drawn through the intersections of the two conics.

35. The equation

$$\text{Disct. } (\mathfrak{A}, \mathfrak{B}, \mathfrak{C}, \mathfrak{D})(\theta, \theta')^3=0,$$

which is of the fourth order in $\mathfrak{A}, \mathfrak{B}, \mathfrak{C}, \mathfrak{D}$, and of the sixth order as regards (a, b, c, f, g, h) and (a', b', c', f', g', h') respectively, is the condition in order that the two conics may touch each other. Assuming that it is satisfied, the cubic equation in $\theta : \theta'$ has a pair of equal roots; or say there is a twofold root and a onefold root; the twofold root gives the pair of lines drawn from the point of contact to the other two points of intersection, the onefold root gives the pair made up of the common tangent and the line joining the other two points of intersection.

36. In particular, suppose that the two conics are

$$2(\xi x+\sigma y+\tau z)(\xi' x+\sigma' y+\tau' z)=0,$$
$$2(\lambda x+\mu y+\nu z)(\lambda' x+\mu' y+\nu' z)=0;$$

so that

$$(a, b, c, f, g, h)=(2\xi\xi', 2\sigma\sigma', 2\tau\tau', \sigma\tau'+\sigma'\tau, \tau\xi'+\tau'\xi, \xi\sigma'+\xi'\sigma),$$
$$(a', b', c', f', g', h')=(2\lambda\lambda', 2\mu\mu', 2\nu\nu', \mu\nu'+\mu'\nu, \nu\lambda'+\nu'\lambda, \lambda\mu'+\lambda'\mu),$$
$$(A, B, C, F, G, H)=-(\sigma\tau'-\sigma'\tau, \tau\xi'-\tau'\xi, \xi\sigma'-\xi'\sigma)^2,$$
$$(A', B', C', F', G', H')=-(\mu\nu'-\mu'\nu, \nu\lambda'-\nu'\lambda, \lambda\mu'-\lambda'\mu)^2;$$

and thence also

$$\mathfrak{A}=K = 0,$$

$$\mathfrak{B}=Aa'+\&c.=-2\begin{vmatrix}\lambda, & \mu, & \nu\\ \xi, & \sigma, & \tau\\ \xi', & \sigma', & \tau'\end{vmatrix}\begin{vmatrix}\lambda', & \mu', & \nu'\\ \xi, & \sigma, & \tau\\ \xi', & \sigma', & \tau'\end{vmatrix},$$

$$\mathfrak{C}=A'a+\&c.=-2\begin{vmatrix}\xi, & \sigma, & \tau\\ \lambda, & \mu, & \nu\\ \lambda', & \mu', & \nu'\end{vmatrix}\begin{vmatrix}\xi', & \sigma', & \tau'\\ \lambda, & \mu, & \nu\\ \lambda', & \mu', & \nu'\end{vmatrix},$$

$$\mathfrak{D}=K' = 0;$$

and the equation in (θ, θ') is

$$\mathfrak{B}\theta+\mathfrak{C}\theta'=0;$$

so that, writing $\theta=\mathfrak{C}$, $\theta'=-\mathfrak{B}$, the equation of the pair of lines is

$$\begin{vmatrix} \varrho, & \sigma, & \tau \\ \lambda, & \mu, & \nu \\ \lambda', & \mu', & \nu' \end{vmatrix} \begin{vmatrix} \varrho', & \sigma', & \tau' \\ \lambda, & \mu, & \nu \\ \lambda', & \mu', & \nu' \end{vmatrix} (\varrho x+\sigma y+\tau z)(\varrho' x+\sigma' y+\tau' z)- \begin{vmatrix} \lambda, & \mu, & \nu \\ \varrho, & \sigma, & \tau \\ \varrho', & \sigma', & \tau' \end{vmatrix} \begin{vmatrix} \lambda', & \mu', & \nu' \\ \varrho, & \sigma, & \tau \\ \varrho', & \sigma', & \tau' \end{vmatrix} (\lambda x+\mu y+\nu z)(\lambda' x+\mu' y+\nu' z)=0;$$

and it is easy to see that the left-hand side does in fact break up into factors, and that the equation is

$$\begin{vmatrix} x, & y, & z \\ \mu\tau'-\nu\sigma', & \nu\varrho'-\lambda\tau', & \lambda\sigma'-\mu\varrho' \\ \sigma\nu'-\tau\mu', & \tau\lambda'-\varrho\nu', & \varrho\mu'-\sigma\lambda' \end{vmatrix} \begin{vmatrix} x, & y, & z \\ \mu\tau-\nu\varrho, & \nu\varrho-\lambda\tau, & \lambda\sigma-\mu\varrho \\ \sigma'\nu'-\tau'\mu', & \tau'\lambda'-\varrho'\nu', & \varrho'\mu'-\sigma'\lambda' \end{vmatrix} =0,$$

which of course might have been obtained at once by means of the four points which are the intersection of each component line of the first conic by each component line of the second conic.

37. Suppose that the first conic is

$$(a, b, c, f, g, h)(x, y, z)^2=0,$$

while the second conic is the pair of lines

$$2(\lambda x+\mu y+\nu z)(\lambda' x+\mu' y+\nu' z)=0;$$

then putting, as before,

$$(\theta a+\theta' .\, 2\lambda', \ldots)(x, y, z)^2=0,$$

we have

$$(\mathfrak{A}, \mathfrak{B}, \mathfrak{C}, \mathfrak{D})(\theta, \theta')^2=0,$$

where

$$\begin{aligned} \mathfrak{A} &= K, \\ \mathfrak{B} &= 2(A, B, C, F, G, H)(\lambda, \mu, \nu)(\lambda', \mu', \nu'), \\ \mathfrak{C} &= -(a, b, c, f, g, h)(\mu\nu'-\mu'\nu, \nu\lambda'-\nu'\lambda, \lambda\mu'-\lambda'\mu)^2, \\ \mathfrak{D} &= 0; \end{aligned}$$

and the equation in (θ, θ') is

$$K\theta^2+2(A, \ldots)(\lambda, \mu, \nu)(\lambda', \mu', \nu')\theta\theta'-(a, \ldots)(\mu\nu'-\mu'\nu, \ldots)^2\theta'^2=0,$$

which may be written

$$\{K\theta+(A, \ldots)(\lambda, \mu, \nu)(\lambda', \mu', \nu')\theta'\}^2=\{[(A, \ldots)(\lambda, \mu, \nu)(\lambda', \mu', \nu')]^2+K(a, \ldots)(\mu\nu'-\mu'\nu, \ldots)^2\}\theta'^2$$
$$=(A, \ldots)(\lambda, \mu, \nu)^2.(A, \ldots)(\lambda', \mu', \nu')^2.\theta'^2,$$

that is,

$$K\theta=[\pm\sqrt{(A, \ldots)(\lambda, \mu, \nu)^2}\sqrt{(A, \ldots)(\lambda', \mu', \nu')^2}-(A, \ldots)(\lambda, \mu, \nu)(\lambda', \mu', \nu')]\theta';$$

or we may assume

$$\theta = \pm\sqrt{(A, ..\lambda, \mu, \nu)^3}\sqrt{(A, ..\lambda', \mu', \nu')^3} - (A, ..\lambda, \mu, \nu\lambda', \mu', \nu'), \quad \theta' = K,$$

so that the conic

$$\{\pm\sqrt{(A, ..\lambda, \mu, \nu)^3}\sqrt{(A, ..\lambda', \mu', \nu')^3} - (A, ..\lambda, \mu, \nu\lambda', \mu', \nu')\}(a, ...x, y, z)^3 + 2K(\lambda x + \mu y + \nu z)(\lambda' x + \mu' y + \nu' z) = 0$$

breaks up into a pair of lines.

Putting for shortness

$$\pm\sqrt{(A, ..\lambda, \mu, \nu)^3}\sqrt{(A, ..\lambda', \mu', \nu')^3} - (A, ..\lambda, \mu, \nu\lambda', \mu', \nu') = \Omega,$$

the coefficients on the left-hand side of the equation are

$$(\Omega a + 2K\lambda\lambda', .. \Omega f + K(\mu\nu' + \mu'\nu), ..),$$

whence, after all reductions, the inverse function is

$$\{(A, ..\lambda, \mu, \nu\xi, \eta, \zeta)\sqrt{(A, ..\lambda', \mu', \nu')^3} \mp (A, ..\lambda', \mu', \nu'\xi, \eta, \zeta)\sqrt{(A, ..\lambda, \mu, \nu)^3}\}^2,$$

and the remainder of the process of decomposition is effected without difficulty.

ADDITION, 18 December, 1862.

The formulæ II. and II. (bis) each of them give the tangents of the conic $(a, ...x, y, z)^3 = 0$ at the ineunts of intersection with the line $\xi x + \eta y + \zeta z = 0$. A very elegant formula for these ineunts themselves was communicated to me by Mr. SPOTTISWOODE, and I have since found that the same or an equivalent formula is made use of by M. ARONHOLD in his recent valuable memoir, "Ueber eine neue algebraische Behandlungsweise der Integrale irrationaler Differentiale, &c.", Crelle, t. lxii. pp. 95–145 (1862). The formula is as follows, viz. for the conic and line,

$$(a, b, c, f, g, h\,x, y, z)^3 = 0$$
$$\xi' x + \eta' y + \zeta' z = 0,$$

then

$$x : y : z =$$
$$(l\xi' + m\eta' + n\zeta')\frac{1}{2\sqrt{\varphi}}\frac{d\varphi}{d\xi'} + \eta'(gl + fm + cn) - \zeta'(hl + bm + fn) + l\sqrt{\varphi},$$
$$: (l\xi' + m\eta' + n\zeta')\frac{1}{2\sqrt{\varphi}}\frac{d\varphi}{d\eta'} + \zeta'(al + hm + gn) - \xi'(gl + fm + cn) + m\sqrt{\varphi},$$
$$: (l\xi' + m\eta' + n\zeta')\frac{1}{2\sqrt{\varphi}}\frac{d\varphi}{d\zeta'} + \xi'(hl + bm + fn) - \eta'(al + hm + gn) + n\sqrt{\varphi};$$

where

$$\varphi = \begin{vmatrix} \xi', & \eta', & \zeta' \\ \xi, & a, & h, & g \\ \eta', & h, & b, & f \\ \zeta, & g, & f, & c \end{vmatrix} = -(A, B, C, F, G, H)(\xi', \eta', \zeta')^2$$

So that $\frac{1}{2}\frac{d\varphi}{d\xi'}$, $\frac{1}{2}\frac{d\varphi}{d\eta'}$, $\frac{1}{2}\frac{d\varphi}{d\zeta'}$ are respectively

$$= -(A\xi' + H\eta' + G\zeta'),\ -(H\xi' + B\eta' + F\zeta') - G\xi' + F\eta' + C\zeta',$$

and where l, m, n are supernumerary arbitrary quantities.

XXX. *Appendix to the Account of the Earthquake-Wave Experiments made at Holyhead.*

By Robert Mallet, *C.E., F.R.S.*

Received March 27,—Read May 8, 1862.

I am now enabled to fulfill the intention expressed (vol. cli. p. 678) in concluding the above 'Account,' as read to the Royal Society, having since then completed a series of experiments upon the compression of specimens of the Holyhead Rocks, and determined their moduli of elasticity. These experiments were made upon cubes cut from solid and perfect pieces of the rocks by the lapidary's wheel, each 0·707 inch upon the edge—each side, therefore, presenting a surface of 0·5 square inch,—and the utmost care being taken to preserve perfect parallelism between the opposite boundary planes, so that, when compressed between hardened steel surfaces, fracture should not result by inequality of pressure.

The compressions were made at the Royal Arsenal, Woolwich, with the very accurate and excellent machine used for testing compression and extension of metals in the gun-factory; and I have to express my thanks to Lieut.-Col. Anderson, C.E., the Superintendent of that department, for the valuable assistance afforded me through his attention.

The specimens operated on consisted of two each from the following four classes, namely, the hardest and the softest slate-rock, the hardest and the softest quartz-rock, which occur within the range or neighbourhood of my experimental explosions at Holyhead; and from each of these classes or varieties of the two rocks, cubic specimens were compressed, 1st, in a direction transverse to the plane of lamination, 2nd, parallel to the same, all the cubes being so cut out of the rock that two sides were, *quam prox.*, parallel to the plane of natural lamination or jointing. The load (50 lbs.) first applied was considered zero, being only sufficient to ensure a complete bearing in all parts of the instrument. The subsequent loads advanced by 1000 lbs. per square inch of surface at a time, up to the crushing of the specimen; and at each fresh load the amount of compression was measured by beam-callipers, with instrumental arrangements that admitted of reading space to ·0005 of an inch.

The experimental results, as obtained, are recorded in the following Tables, from No. I. to No. VIII. inclusive; and in the succeeding Tables IX. and X., the results of the former are compared, and the mean compression deduced for each 1000 lbs. of pressure applied upon a prism of each of the four classes of rock (two of slate and two of quartz), of one inch square surface, and one inch in height, and under both conditions as to the relative direction of pressure and of lamination.

TABLE I.—Holyhead-Rock Compression. Experiments A, on Hard Slate; pressure transverse to lamination.

No. of experiment.	Pressure due to the unit of surface = 1 square inch.	Compression readings of the column of 0·707 inch.	Compression readings due to the successive loads.	Total compressions produced by the load on column of 0·707 inch.	Total compressions reduced to a column of unit height = 1 inch.
	lbs.	in.	in.	in.	in.
1.	50	·085	·000	·000	·0000
2.	1,000	·081	·004	·004	·0052
3.	2,000	·078+	·003−	·007	·0091
4.	3,000	·078+	·000	·007	·0091
5.	4,000	·078	·000+	·007	·0091
6.	5,000	·078	·000	·007	·0091
7.	6,000	·077+	·001−	·007	·0091
8.	7,000	·077	·000+	·008	·0104
9.	8,000	·076+	·001−	·008	·0104
10.	9,000	·076+	·000	·008	·0104
11.	10,000	·076+	·000	·008	·0104
12.	11,000	·076	·000+	·008	·0104
13.	12,000	·076	·000	·009	·0117
14.	13,000	·075+	·001−	·009	·0117
15.	14,000	·075+	·000	·009	·0117
16.	15,000	·075+	·000	·009	·0117
17.	16,000	·075	·000+	·009	·0117
18.	17,000	·075	·000	·009	·0117
19.	18,000	·075	·000	·009	·0117
20.	19,000	·075	·000	·010	·0130
21.	20,000	·074+	·001−	·010	·0130
22.	21,000	·074+	·000	·010	·0130
23.	22,000	·074	·000+	·010	·0130
24.	23,000	·074	·000	·011	·0143
25.	24,000	Crushed.		·011	·0143

TABLE II.—Holyhead-Rock Compression. Experiments B, on Hard Slate; pressure parallel to lamination.

1.	50	·130	·000	·000	·0000
2.	1,000	·120	·010	·010	·0130
3.	2,000	·100	·020	·030	·0390
4.	3,000	·099+	·001−	·031+	·0403+
5.	4,000	·098	·001+	·032	·0416
6.	5,000	·097	·001	·032	·0416
7.	6,000	·096	·001	·032	·0416
8.	7,000	·094	·002	·036	·0468
9.	8,000	·092+	·002−	·038+	·0494
10.	9,000	·092+	·000	·038+	·0494
11.	10,000	·092+	·000	·038+	·0494
12.	11,000	·092	·000+	·038+	·0494
13.	12,000	·092	·000	·038+	·0494
14.	13,000	·092	·000	·038+	·0494
15.	14,000	·092	·000	·038+	·0494
16.	15,000	·090	·002	·040	·0520
17.	16,000	·089	·001	·041	·0533
18.	17,000	·086	·003	·044	·0572
19.	18,000	·085+	·001−	·045+	·0585+
20.	19,000	·085+	·000	·045+	·0585+
21.	20,000	·085+	·000	·045+	·0585+
22.	21,000	·085	·000+	·045+	·0585+
23.	22,000	·085	·000	·045+	·0585+
24.	23,000	·085	·000	·045+	·0585+
25.	24,000	·082	·003	·048	·0624
26.	25,000	·082	·000	·048	·0624
27.	26,000	·080	·002	·050	·0650
28.	27,000	·077	·003	·053	·0689
29.	27,000+	Crushed.		·053	·0689

TABLE III.—Holyhead-Rock Compression. Experiments C, on Hard Quartz; pressure transverse to lamination.

No. of experiment.	Pressure due to the unit of surface = 1 square inch.	Compression readings of the column of 0·707 inch.	Compression readings due to the successive loads.	Total compressions produced by the load on column of 0·707 inch.	Total compressions reduced to a column of unit height = 1 inch.
	lbs.	in.	in.	in.	in.
1.	50	·100	·000	·000	·0000
2.	1,000	·097	·003	·003	·0039
3.	2,000	·095+	·002−	·003	·0039
4.	3,000	·095+	·000	·003	·0039
5.	4,000	·095+	·000	·003	·0039
6.	5,000	·095+	·000	·003	·0039
7.	6,000	·095	·000+	·003	·0039
8.	7,000	·095	·000	·003	·0039
9.	8,000	·095	·000	·005	·0065
10.	9,000	·094	·001	·006	·0078
11.	10,000	·093+	·001−	·006	·0078
12.	11,000	·093+	·000	·006	·0078
13.	12,000	·093+	·000	·006	·0078
14.	13,000	·093	·000+	·006	·0078
15.	14,000	·093	·000	·006	·0078
16.	15,000	·093	·000	·006	·0078
17.	16,000	·093	·000	·007	·0091
18.	17,000	·092+	·001−	·007	·0091
19.	18,000	·092	·000+	·007	·0091
20.	19,000	·092	·000	·008	·0104
21.	20,000	·091+	·001−	·009+	·0117+
22.	21,000	·088	·003+	·012	·0156
23.	22,000	·083+	·005−	·012	·0156
24.	23,000	·083+	·000	·012	·0156
25.	24,000	·083+	·000	·012	·0156
26.	25,000	·083	·000+	·012	·0156
27.	26,000	·083	·000	·017	·0221
28.	27,000	·082+	·001−	·017	·0221
29.	28,000	·082+	·000	·017	·0221
30.	29,000	·082+	·000	·017	·0221
31.	30,000	·082	·000+	·017	·0221
32.	31,000	·082	·000	·017	·0221
33.	32,000	·082	·000	·018	·0234
34.	33,000	·081+	·001−	·018	·0234
35.	34,000	·081	·000+	·019	·0247
36.	35,000	·080+	·001−	·019	·0247
37.	36,000	·080	·000+	·020	·0260
38.	36,000+	Crushed.		·020	·0260

TABLE IV.—Holyhead-Rock Compression. Experiments D, on Hard Quartz; pressure parallel to lamination.

1.	50	·106	·000	·000	·0000
2.	1,000	·106	·000	·000	·0000
3.	2,000	·106	·000	·000	·0000
4.	3,000	·106	·000	·000	·0000
5.	4,000	·106	·000	·000	·0000
6.	5,000	·102	·004	·004	·0052
7.	6,000	·100+	·002−	·004	·0052
8.	7,000	·100+	·000	·004	·0052
9.	8,000	·100+	·000	·004	·0052
10.	9,000	·100	·000+	·004	·0052
11.	10,000	·100	·000	·004	·0052
12.	11,000	·100	·000	·006	·0078
13.	12,000	·098+	·002−	·006	·0078
14.	13,000	·098	·000+	·008	·0104
15.	14,000	·097	·001	·009	·0117
16.	15,000	·096	·001	·010	·0130
17.	16,000	·093	·003	·013	·0169
18.	17,000	·092	·001	·014	·0182
19.	18,000	·090+	·002−	·014	·0182
20.	19,000	·090	·000+	·016	·0208
21.	20,000	Crushed.		·016	·0208

TABLE V.—Holyhead-Rock Compression. Experiments E, on Soft Slate; pressure transverse to lamination.

No. of experiment.	Pressure due to the unit of surface =1 square inch.	Compression readings of the column of 0·707 inch.	Compression readings due to the successive loads.	Total compressions produced by the load on column of 0·707 inch.	Total compressions reduced to a column of unit height =1 inch.
	lbs.	in.	in.	in.	in.
1.	50	·088	·000	·000	·0000
2.	1,000	·087	·001	·001	·0014
3.	2,000	·086+	·001−	·001	·0014
4.	3,000	·086	·000+	·002	·0029
5.	4,000	·085	·001	·002	·0029
6.	5,000	·085	·000	·003	·0043
7.	6,000	·079	·006	·009	·0129
8.	7,000	·077+	·002−	·009	·0129
9.	8,000	·077+	·000	·009	·0129
10.	9,000	·077	·000+	·009	·0129
11.	10,000	·077	·000	·009	·0129
12.	11,000	·077	·000	·011	·0158
13.	12,000	·075	·002	·013	·0187
14.	13,000	·060	·015	·028	·0404
15.	14,000	·050	·010	·038	·0548
16.	15,000	Crushed.		·038	·0548

NOTE.—The cube E was 0·693 inch on the side, and the necessary reductions have been made in column 2 and subsequent ones.

TABLE VI.—Holyhead-Rock Compression. Experiments F, on Soft Slate; pressure parallel to lamination.

1.	50	·107	·000	·000	·0000
2.	1000	·105	·002	·002	·0029
3.	2000	·102+	·003−	·002	·0029
4.	3000	·102	·000+	·002	·0029
5.	4000	·102	·000	·005	·0072
6.	5000	·099	·003	·008	·0115
7.	6000	·097	·002	·010	·0147
8.	7000	·089	·008	·018	·0259
9.	8000	·080	·009	·027	·0389
10.	8000+	Crushed.		·027	·0389

NOTE.—The cube F was 0·693 inch on the side, and the necessary reductions have been made in column 2 and subsequent ones.

TABLE VII.—Holyhead-Rock Compression. Experiments G, on Soft Quartz; pressure transverse to lamination.

1.	50	·093	·000	·000	·0000
2.	1,000	·093	·000	·000	·0000
3.	2,000	·093	·000	·000	·0000
4.	3,000	·090	·003	·003	·0043
5.	4,000	·086+	·004−	·003	·0043
6.	5,000	·086+	·000	·003	·0043
7.	6,000	·086	·000+	·003	·0043
8.	7,000	·086	·000	·007	·0101
9.	8,000	·085+	·001−	·007	·0101
10.	9,000	·085+	·000	·007	·0101
11.	10,000	·085	·000+	·008	·0115
12.	11,000	·084	·001	·009	·0129
13.	12,000	·081	·003	·012	·0176
14.	13,000	·068	·013	·025	·0359
15.	14,000	·060	Crushed before being fully loaded.		

NOTE.—The cube G was 0·694 inch on the side, and the necessary reductions have been made in column 2 and subsequent ones.

TABLE VIII.—Holyhead-Rock Compression. Experiments H, on Soft Quartz; pressure parallel to lamination.

No. of experiment.	Pressure due to the unit of surface =1 square inch.	Compression readings of the column of 0·707 inch.	Compression readings due to the successive loads.	Total compressions produced by the load on column of 0·707 inch.	Total compressions reduced to a column of unit height =1 inch.
	lbs.	in.	in.	in.	in.
1.	50	·170	·000	·000	·0000
2.	1,000	·144	·026	·026	·0374
3.	2,000	·101+	·043−	·069	·0992
4.	3,000	·101	·000+	·069	·0993
5.	4,000	·100	·001	·070	·1007
6.	5,000	·099	·001	·071	·1021
7.	6,000	·098	·001	·072	·1036
8.	7,000	·049	·049	·121	·1741
9.	7,000 +	Crushed before the increased load was applied.			

NOTE.—The cube H was 0·695 inch on the side, and the necessary reductions have been made in column 2 and subsequent ones.

TABLE IX.—Holyhead-Rock Compression. Slate Rock.—Results of compression compared. Column of unit length =1 inch.

No. of experiment.	Pressure in pounds on unit of surface =1 square inch.	A. Hard slate across lamina.	B. Hard slate with the lamina.	E. Soft slate across lamina.	F. Soft slate with the lamina.
	lbs.	in.	in.	in.	in.
1.	50	·0000	·0000	·0000	·0000
2.	1,000	·0052	·0130	·0014	·0029
3.	2,000	.....	·0390		
4.	3,000	.....	·0403	·0029	
5.	4,000	.....	·0416	.....	·0072
6.	5,000	·0091	.....	·0043	·0115
7.	6,000	.....	.....	·0129	·0147
8.	7,000	·0104	·0468	.....	·0259
9.	8,000	.....	·0494	.....	·0389
10.	9,000	.....	.....	.....	Crushed.
11.	10,000				
12.	11,000	.....	.....	·0158	
13.	12,000	·0117	.....	·0187	
14.	13,000	.....	.....	·0404	
15.	14,000	.....	.....	·0548	
16.	15,000	.....	·0520	Crushed.	
17.	16,000	.....	·0533		
18.	17,000	.....	·0572		
19.	18,000	.....	·0585		
20.	19,000	·0130			
21.	20,000				
22.	21,000				
23.	22,000				
24.	23,000	·0143			
25.	24,000	Crushed.	·0624		
26.	25,000				
27.	26,000	.....	·0650		
28.	27,000	.....	·0689		
29.	28,000	.....	Crushed.		
30.	29,000				
Mean compression for each 1000 lbs. on unit of surface		in. ·0006217 up to 23,000 lbs.	in. ·0025000 up to 26,000 lbs.	in. ·0039144 up to 14,000 lbs.	in. ·0037000 up to 7000 lbs.

TABLE X.—Holyhead-Rock Compression. Quartz Rock.—Results of Compression compared. Column of unit length =1 inch.

No. of experiment.	Pressure in pounds on unit of surface =1 square inch.	C. Hard quartz across lamina.	D. Hard quartz with the lamina.	G. Soft quartz across lamina.	H. Soft quartz with the lamina.
	lbs.	in.	in.	in.	in.
1.	50	·0000	·0000	·0000	·0000
2.	1,000	·0039	.....	.....	·0374
3.	2,000	.....	.....	.....	·0992
4.	3,000	.....	.....	·0043	·0993
5.	4,000	.....	.....	.....	·1007
6.	5,000	.....	·0052	.....	·1021
7.	6,000	.....	.....	.....	·1036
8.	7,000	.....	.....	·0101	·1741
9.	8,000	·0065	.....	.....	Crushed.
10.	9,000	·0078	.....	.....	
11.	10,000	.....	.....	·0115	
12.	11,000	.....	·0078	·0129	
13.	12,000	.....	.....	·0176	
14.	13,000	.....	·0104	·0359	
15.	14,000	.....	·0117	Crushed.	
16.	15,000	.....	·0130		
17.	16,000	·0091	·0169		
18.	17,000	.....	·0182		
19.	18,000	.....			
20.	19,000	·0104	·0208		
21.	20,000	·0117	Crushed.		
22.	21,000	·0156			
23.	22,000	.....			
24.	23,000	.....			
25.	24,000	.....			
26.	25,000	.....			
27.	26,000	·0221			
28.	27,000	.....			
29.	28,000	.....			
30.	29,000	.....			
31.	30,000	.....			
32.	31,000	.....			
33.	32,000	·0234			
34.	33,000	.....			
35.	34,000	·0247			
36.	35,000	.....			
37.	36,000	·0260			
38.	37,000	Crushed.			
Mean compression for each 1000 lbs. on unit of surface.		in. ·0007085 up to 35,000 lbs.	in. ·0010947 up to 19,000 lbs.	in. ·0014666 up to 12,000 lbs.	in. ·0172666 up to 6000 lbs.

An examination of these Tables presents some remarkable and, so far as I am aware, now for the first time observed results.

As might have been expected, the quartz-rock is much less compressible generally than the slate-rock, with this exception, however, that the softest specimens of quartz-rock, and those alone, are much more compressible than the softest slate, when both are compressed in the direction of or parallel to the lamination.

In this direction of compression, the hardest slate is more than double as compressible as the hardest quartz.

When compressed transverse to the lamina, however, the hard slate and hard quartz prove to have very nearly the same coefficient of compressibility, which is very small for both; while the softest slate and the softest quartz, compressed in the same way (transverse to lamina), have also nearly the same coefficient of compressibility, but one about four times as great as for the hardest like rocks.

These facts point towards the circumstance of the original deposit and formation of these rocks as their efficient causes. Both rocks consist of particles more or less wedge-shaped and flat, angular fragments more or less crystalline, deposited together, with their larger dimensions in the planes of lamination, which lamination has been produced by enormous compression in a direction transverse to its planes. Hence the mass of these rocks has *already* been subjected to enormous compression in the *same* direction as that in which we now find their further compressibility the least. But, besides that we might from *this* cause alone anticipate a higher compressibility when the pressure is applied to them parallel to the lamination, another condition comes into play; their aggregation of flat, *wedge-shaped* particles, when thus pressed edgeways, tends powerfully to their mutual lateral expansion, and hence to their giving way in the line of pressure.

The *per-saltum* way in which all the specimens of both rocks yield, in whatever direction pressed, is another noteworthy circumstance. On examining the Tables I. to VIII. it will be seen that the compressions do not constantly advance with the pressure, but that, on the contrary, the rock occasionally suffers almost no sensible compression for several successive increments of pressure, and then gives way all at once (though without having lost cohesion, or having its elasticity permanently impaired) and compresses thence more or less for three or four or more successive increments of pressure, and then holds fast again, and so on. This phenomenon is probably due to the mass of the rock being made up of intermixed particles of several different simple minerals, having each specific differences of hardness, cohesion, and mutual adhesion, and which are, in the order of their resistances to pressure, in succession broken down, before the final disruption of the whole mass (weakened by these minute internal dislocations) takes place.

Thus it would appear that the micaceous plates and aluminous clay-particles interspersed through the mass give way first. The chlorite in the slate, and probably felspar-crystals in the quartz-rock, next, and so on in order, until finally the elastic skeleton of silex gives way, and the rock is crushed. It is observable, also, that this successive disintegration does not occur at equal pressures, in the same quality and kind of rock, when compressed transverse and parallel to the lamination. It follows from this constitution of these (and probably of all) rocks that very different powers of transmitting wave-impulses must arise when the originating forces vary considerably in amount of primary compression. It is almost superfluous also to point out the great differences in wave-transmissive power in directions transverse and parallel to lamination that these

experiments disclose. They prove to us that, in an earthquake shock of given original power, the vibrations will have the largest amplitude when transmitted in the line of the lamination, but may be propagated with the greatest velocity in directions transverse to the same, *assuming in both cases the rock solid and unshattered.*

In the following Table XI. the general results are deduced, and the *mean compressions* for each of the rocks calculated, and finally the moduli of elasticity are obtained in pounds and in feet; the specific gravities adopted in calculating the latter being those given in the body of the paper, as follows:—

	sp. gr.	Weight of a prism 1 foot long and 1 inch square. lbs.
Hardest slate	2·763	1·1992
Softest slate	2·746	1·1918
Hardest quartz	2·656	1·1528
Softest quartz	2·653	1·1515
Mean for slate	2·7545	1·1955
Mean for quartz	2·6545	1·1522
General mean for both rocks	2·7045	1·1739

The load on the unit of surface (1 square inch) at which the elastic limit of the rock is passed, and that at which it is finally crushed, together with the modulus of cohesion or resistance to compression, are also given, and will be useful to the engineer and architect. In the last column the value of my own modification of PONCELET'S coefficient T, (la force vive de rupture) is calculated in foot pounds, and represents the relative work done at fracture in each case.

Table XI.—Holyhead-Rock Compression.

General results reduced, Modulus of Cohesion and of Elasticity, &c.—Slate and Quartz.

No.	Class of Rock, and direction of pressure in relation to structure.	Coefficient of compression on unit surface for 1000 lbs.	Elastic limit for compression.	Crushing load on the unit of surface.	Modulus of cohesion (compression).	Modulus of elasticity.	Modulus of elasticity. L.	Coefficient. T_r.
		in.	lbs.	lbs.	ft.	lbs.	ft.	ft. lbs.
1.	Slate, *hardest, across* lamination	·0006217	22,000	24,000	20,014	8,042,464	6,706,524	1·2432
2.	Quartz, *hardest, across* lamination	·0007085	32,000	37,000	32,095	7,057,163	6,121,758	2·1830
3.	Slate, *hardest, parallel* to lamination	·0025000	18,000	27,000	22,515	2,000,000	1,667,778	5·6241
4.	Quartz, *hardest, parallel* to lamination	·0010947	17,000	20,000	17,349	4,567,461	3,962,013	1·8240
5.	Slate, *softest, across* lamination	·0039144	12,000	15,000	12,586	1,277,335	1,071,769	4·8930
6.	Quartz, *softest, across* lamination	·0014666	11,000	14,000	12,158	3,409,246	2,960,699	1·7108
7.	Slate, *softest, parallel* to lamination	·0037000	6,000	9,000	7,552	1,351,351	1,133,874	2·7747
8.	Quartz, *softest, parallel* to lamination	·0172666	7,000	8,000	6,948	289,576	251,477	11·6112
	Calculated means.							
9.	Slate, mean for hard and soft, *across* lamination	·0022680	17,000	19,500	16,311	2,204,585	1,844,069	3·6855
10.	Quartz, mean for hard and soft, *across* lamination	·0010875	16,500	25,500	22,132	4,597,701	3,990,455	2·3103
11.	Slate, mean for hard and soft, *parallel* to lamination	·0031000	12,000	18,000	15,056	1,612,903	1,349,145	4·6494
12.	Quartz, mean for hard and soft, *parallel* to lamination	·0091806	12,000	14,000	12,151	544,627	472,684	10·7100
	Calculated mean of means.							
13.	Slate, hard and soft, mean for both directions (Nos. 9 & 11)	·0026840	14,500	18,750	15,684	1,862,880	1,566,541	4·1914
14.	Quartz, hard and soft, mean for both directions (Nos. 10 & 12)	·0051340	16,750	19,750	17,141	973,899	845,252	8·4490
15.	General mean for Slate and Quartz, hard and soft, and in both directions (Nos. 13 & 14)	·0039090	15,625	19,250	16,398	1,279,099	1,089,613	6·2697

To apply the results thus obtained to those of experimental wave-transmission at Holyhead.

Poisson has shown* that the velocity of wave-transmission (sound) in longitudinal vibrations of elastic prisms is

$$V^2=\frac{glq}{p} \quad . \quad . \quad .

and for the three preceding velocities, α has the following values:—

ft. per sec.

$$1\ldots V'=1089\ldots\ldots \alpha=\frac{1089}{\sqrt{2917262}}=\frac{1089}{1708}=0{\cdot}637$$

$$2\ldots V'=1352\ldots\ldots \alpha=\frac{1352}{\sqrt{2917262}}=\frac{1352}{1708}=0{\cdot}791$$

$$3\ldots V'=1220\ldots\ldots \alpha=\frac{1220}{\sqrt{2917262}}=\frac{1220}{1708}=0{\cdot}714$$

The actual velocity of wave-transmission in the slate and quartz together, therefore, was to the theoretic velocity due to the solid material as

$$\alpha:\sqrt{g} \text{ or } 0{\cdot}714:5{\cdot}774, \text{ or } 1{\cdot}00:7{\cdot}946.$$

From which it results that *nearly seven-eighths* of the full velocity of wave-transmission due to the material is lost by reason of the heterogeneity and discontinuity or shattering of the rocky mass, as it is found piled together in nature.

This loss would be larger with still smaller originating impulses, and *vice versâ*, but in what proportion we are not at present in a position to know.

If we may for a moment allude to final causes, we cannot but be struck with this beneficent result (amongst others) arising from the shattered and broken-up condition of all the rocky masses forming the habitable surface of our globe,—that the otherwise enormous transit-velocity of the wave-form in earthquake shocks is by this simple means so reduced.

That this retardation is mainly effected by the multiplied subdivisions of the rock, and in a very minor degree by differences in the elastic moduli of rock of different species, is apparent on examining the Tables IV. and V. of the previous part of this Report referring to the experiments at Holyhead.

Although, therefore, we are now enabled, from what precedes, to calculate values for α, for the slate rocks and for the quartz of Holyhead, separately, and thus obtain separate values for V′, for *each* of those rocks; the result would probably be more or less delusive, as we have no possible means of deciding what is the relative amount of shattering and discontinuity, for equal horizontal distances, in each of these two rocks, nor what the relative retarding powers of planes of separation running in variable directions, and at all possible angles across the line of wave-transit, as compared with their retarding powers if either all transverse to, or all in the same direction as, the wave-path.

The greatest possible mean velocity of wave-propagation, *in rock as perfectly solid and unshattered* as our experimental cubes, is determinable for both slate and quartz in the two directions of transmission, viz. transverse and in the line of lamination, from equation (III.), and the mean values of L in Nos. 9 and 10, and 11 and 12, Table XI., as follows:—

ft. per sec.

Mean of slate and quartz transverse to lamination ... $V=5{\cdot}674\sqrt{2917262}=9691$

Mean of slate and quartz in line of lamination ..... $V=5{\cdot}674\sqrt{910914}=5415$

This great difference of velocity, due to the difference in the molecular properties of the material of the rocks in their opposite directions, is, as our Holyhead experiments prove, almost wholly obliterated by the vastly increased degree of discontinuity and shattering, in the directions approaching that of lamination, or transverse to the wave-path in the first case.

It is necessary to guard against any misconception as to the import of this result. The fact ascertained and just enunciated is this, that the velocity of wave-transmission is greater in the material of these rocks in a direction across their lamination than in one longitudinal to the same, provided or *assuming the material be perfectly unshattered in both*—as homogeneous, in fact, as the small specimen-cubes experimented upon. And were the whole mass of the rock, as it lies in its mountain-bed, as homogeneous as such cubes, then the velocity of wave-transmission would *actually* be greater *across* long ranges of natural lamination, than edgeways to them. The opposite, however, is often the case; the wave-transit period is slower as the range of rocky mass is more shattered, discontinuous, and dislocated.

These conditions affect rocks in nature most in or about their planes of bedding, lamination, &c., and hence most retard wave-impulses transverse to these planes; so that the *more rapid wave-transmissive power of the material* of the rock in a direction transverse to the lamination *may be more than counterbalanced by the discontinuity* of its mass transverse to the same direction.

The results of Wertheim, on the transmission of sound in timber, proved the velocity to be greatest in a direction longitudinal to the fibres and annual rings of wood; less in a direction perpendicular to the same, and from the centre of the tree radially towards its exterior; and least of all in a direction, *quam prox.*, parallel to the annual rings, and perpendicular to the longitudinal fibres; that is to say, that in each case the velocity of sound was rapid in proportion to the less compressibility of the wood in the same direction. His results might seem at first to conflict with those which I have announced. Any such conclusion, however, would be a mistake; on the contrary, my results perfectly analogize with those above alluded to. The difference between the cases is, that wood in mass, however large, is practically homogeneous and unshattered, and that *its direction of least compressibility is longitudinal to its laminæ* (or annual rings); whereas *the direction of least compressibility of rock is transverse to its laminæ* (which have been already powerfully compressed in this direction). In fact, as respects the point here in question, there is no true analogy *in structure* between the lamination (by annual rings) of wood, and the lamination or bedding of rock.

It follows from what precedes, that earthquakes and rocks as both actually occur in nature—the rocks being of a stratified or laminated form (generally all sedimentary rocks)—must present the following conditions as to rate of transit of shock:—

1st. If such rocks were perfectly unshattered, and the beds or laminæ in absolute contact, the shock would be transmitted more rapidly across these than in their own direction.

The difference is more in favour of the transverse line, in proportion as the rock is made up more of angular sedimentary particles of very unequal dimensions, the longest being parallel to the general lamination, and in proportion as the imbedding paste is softer in relation to such particles.

Some sedimentary rocks no doubt exist, made up of particles perfectly uniform and equal in all three dimensions, and without imbedding paste—such as the lithographic stones of Germany, the Apennine marl-beds, &c., in which (assuming the above condition as to continuity) the transit-period would probably be alike in all directions.

2nd. The actual amount of shattering and discontinuity in nature being usually greatest, upon the whole, in planes parallel to bedding or lamination, the transit-rate of shock is most generally fastest in the line of the beds or lamination, rather than across them.

Or, at least, this latter condition may interfere with the former to the extent of partial, complete, or more than complete obliteration.

I am not aware that experiments have previously been made at all upon the compressibility, &c. of the slate- and quartz-rocks of Holyhead; and as these rocks are being employed there upon a vast scale for submarine building works, it may not be out of place to draw a few conclusions of a character useful to the practical engineer from the data that have been obtained. Some conclusions may be drawn which are applicable to all classes of laminated rocks in the hands of the engineer.

It is a very prevalent belief that slate-rock (for example), in the form of the sawed roofing-slate of Anglesea or of Valentia (Ireland), will bear a much greater compressive load when the pressure is in the direction of the laminæ, than in one across them. This the preceding experiments prove to be wholly a mistake—one that has very probably arisen from some vague notion of an analogy with timber compressed the end-way of the grain.

It is now certain that Silurian slates and quartz-rock, and probably all sedimentary laminated rocks, whether with cleavage or not, are much weaker to resist a crushing force edgeways to the lamina, than across the same, and that the range of compressibility is much greater, for equal loads, in the former direction.

The fact now ascertained, as to the great relative compressibility of laminated rock in the direction of the laminæ, also points out the reason of the great bearing-power to sustain impulsive loads, which the toughest and most cohesive examples of slate-rocks, such as the slates of Caernarvonshire, present; for there can be no grounds to doubt that the high compressibility of rocks of this structure in the plane of the lamina is also accompanied with a high coefficient of extensibility, although probably confined within much narrower limits as to incipient injury to perfect continuity.

My experiments point out that the Silurian slate of Holyhead (the mean both of the hard and the soft) is crushed by a load applied across the lamina of about 1250 tons per square foot, and that its molecular arrangement is permanently injured at a little more than 1000 tons per square foot.

The quartz-rock (the mean of both hard and soft) is crushed by a load, applied in the same manner, of 1630 tons per square foot, and its molecular arrangement is permanently injured at less than 1000 tons per square foot. The quartz-rock gives the highest measure of ultimate resistance, but it is the less trustworthy material when loaded heavily.

Neither of these sorts of rock, if loaded so as to be pressed *in the direction of the lamina*, would sustain more than about 0·7 of the above loads at the crushing-point and at that of permanent injury, respectively. From the extreme inequality found within narrow limits in both rocks as quarried, neither should be trusted for safe load in practice with more than about $\frac{1}{10}$th of the mean load that impairs their molecular arrangement, as ascertained from selected specimens, or (say) not to more than 50 tons per square foot for passive or 25 tons per square foot for impulsive loads.

The high relative compressibility of laminated rocks in the direction of the lamina might probably be made advantageous use of, where they are employed as a building material, for the construction of revetment or other walls of batteries exposed to the stroke of cannon-shot, by building the work (under suitable arrangements to obviate splitting up) with the planes of the laminæ in the direction of the line of fire, *i. e.* perpendicular to the faces of the work; for on inspecting the last column in Table XI., which contains the values of T, under the several conditions of rock and of compression, it is at once apparent how much greater is the work done in crushing the slates and the quartz in their toughest and most compressible direction, *i. e.* in the direction of the laminæ,—*twice as much work* being, upon the average, consumed in crushing the rock in this direction as suffices to destroy its coherence in the one transverse to the laminæ, and the difference in the two, in the case of the softest quartz (Nos. 6 & 8), being as much as about 5 to 1.

It would be unsuitable, however, to the present memoir here to pursue further such practical deductions suggested by the results experimentally obtained.

XXXI. *On the Theory of the Motion of Glaciers.*

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ALMOST all the numerous discussions which have taken place during the last twenty years respecting our theories of glacial motion have had for their object the assertion of some particular view, rather than the establishment of a complete and sufficient theory founded on well-defined hypotheses and unequivocal definitions, together with a careful comparison of the results of accurate theoretical investigation with those of direct observation. Each of these views has been regarded, in my own opinion improperly, as a *Theory of Glacial Motion*. The Expansion Theory ignored the Sliding Theory, though they were capable of being combined; the latter theory was equally ignored by the Viscous Theory, in which, moreover, instead of the definitions of terms being clear and determinate, no definition of *viscosity* was ever given, though that term designated the fundamental property on which the views advocated by this theory depended. Again, the Regelation Theory is not properly a theory of the motion of glaciers, but a beautiful demonstration of a property of ice, entirely new to us, on which certain peculiarities of the motions of glaciers depend. When we shall have obtained a *Theory of the Motion of Glaciers* which shall command the general assent of philosophers, no qualifying epithet will be required for the word *theory*; it would indeed be inappropriate, as seeming to indicate the continued recognition of some rival theory. If, for instance, it should be hereafter admitted that the sliding of a glacier over its bed and the property of regelation in ice are equally necessary, and, when combined, perfectly sufficient to account for the phenomena of glacial motion, there would be a manifest impropriety, not to say injustice, in selecting either of the terms *sliding* or *regelation* by which to designate this combined theory. I make these remarks because I believe that the preservation of the partial epithets above mentioned has a tendency to prevent our regarding the whole subject in that more general and collective aspect under which it is one of the principal objects of this paper to present it.

This object must necessarily give to the present paper something of the character of a *résumé* of what has hitherto been done, whether it be our purpose to adopt or reject the conclusions of others. There are periods in the history of almost every science when its sound and healthy progress may almost as much demand the refutation of that which is erroneous as the establishment of that which is true. I shall not, however, enter into any review of the past labours of glacialists with respect to exploded theories, but shall only notice those more recent researches and speculations which appear to

me either to demand refutation as erroneous, or admission into any well-founded theory as correct. This treatment of the subject must necessarily lead to a certain repetition as to results already established, and be also of too critical a character, perhaps, with reference to other results in which I may have no confidence. I can only say that, in the present state of glacial theory, such defects must be inherent in any attempt to present it under a more complete and systematic form than it has hitherto, I think, assumed. It is this circumstance, too, which I would especially offer as an apology for the repetition of certain results which I obtained many years ago. Most of them are abstract mathematical results. They are here obtained by a more general analysis of the problem than that formerly employed, and are introduced as essential steps in the development now offered of the theory of the motion of glaciers.

In the first section I shall endeavour to remove the ambiguities which have beset this subject from the want of explicit definitions of certain terms expressing properties of ice on which our theories of glacial motion must essentially depend.

In the second section I shall give a brief statement of the results of experiments which explain the sliding of a mass of ice down a plane of small inclination, with a slow and unaccelerated motion like that of an actual glacier.

In the next section certain propositions are investigated respecting the internal pressures and tensions superinduced within a solid body by external forces which slightly distort it, and produce a small relative displacement of its component particles, or what may be termed a *molecular displacement*.

In the subsequent sections these results are applied to the explanation of crevasses, and to an examination of the theories which have been proposed of the veined structure of glacial ice. Finally, I have shown the importance of the sliding motion in giving efficiency to the internal pressures and tensions to dislocate the glacier, which thus becomes relieved from its internal strain, regaining the continuity of its mass and structure by its property of *regelation* so beautifully exhibited in Dr. TYNDALL's experiment.

SECTION I.—*Definitions and Explanations of Terms.*

1. The external forms of all bodies in nature may be changed in a greater or less degree, and without producing discontinuity in their mass or destruction of their internal structure, by the action of any external forces, the original or undisturbed form from which the change of form is to be estimated being that which the body would assume if acted on by no external forces whatever. This change of form necessarily implies a change in the relative positions of the component particles of the mass, or a certain greater or smaller amount of *molecular mobility*, or power in the particles of moving *inter se*. We may speak either of the general change of the form of the whole body, or of that which takes place in each of its small elementary portions; it is, in fact, in this latter sense that we are obliged to regard it in any accurate investigations, because the change of form for different elements will usually be different. Change of form in an element may or may not be accompanied by a change of its volume. In the first case it

leads to *cubical* extension or compression; in the latter, merely to extension or compression of the surface and not the volume of the element, which may be called *superficial* extension or compression. These changes of volume and form in any element must be produced by the forces acting on it. Thus we may conceive linear extension alone produced at any interior point of the mass by two equal and opposite tensions acting on two elementary component particles there in the direction of the line joining their centres of gravity, while compression alone would result if those tensions were changed into pressures. In such cases extension or compression would be the result of forces which may be called *direct* or *normal* forces. In the case above mentioned, in which the volume and density of every element of the mass remain unaltered, there can be no such direct normal action as that just mentioned. The action must be perpendicular to the normal, and must therefore be a *transversal* or *tangential* action. There would be no tendency to make the contiguous particles approach to or recede from each other, but to cause the one to *slide* tangentially past the other.

If the body have a structure like that of any hard vitreous or crystalline mass, pressure at any point will tend to break or crush the body, and thus to destroy the continuity of its structure. This tendency will be opposed by the *resisting power* of the substance. The tendency of the direct or normal tension is to separate the contiguous particles, and thus produce a finite fissure, or a discontinuity in the mass. It is resisted by the *normal cohesive power*; and in like manner the transverse or tangential action is resisted by the *tangential cohesion*, or that which prevents the component particles from sliding past each other. Again, when the component particles at any point of a body are relatively displaced, they have always a certain tendency to regain their originally undisturbed position; and the force thus excited, considered with reference to the force of displacement at that point, affords a measure of what is called the *elasticity* of the body. Since the force of restitution may vary from zero to the corresponding force of displacement, the elasticity, when measured by their ratio, may vary from zero to unity.

2. We may now define such terms as *solid*, *plastic*, *viscous*, and the like, with all the accuracy which their definitions admit of. We may call a body emphatically a *solid* body when it possesses the following properties:—(1) small extensibility and compressibility, (2) great power of resistance and great cohesive power, both normal and tangential, and (3) great elasticity. It will thus require a comparatively great force to produce any sensible relative displacement among the constituent molecules of the body: if we conceive the force required to become infinitely great, we arrive at absolute *rigidity* as the limit of solidity. Again, we shall best, perhaps, define *plasticity* or *viscosity*, if we suppose the forces of displacement to be such as to produce only a small transverse or tangential displacement of the constituent particles, *i. e.* a superficial, not a cubical, extension or compression. Then, if the force of restitution bear only an inappreciable ratio to the corresponding force of displacement, *i. e.* if the *tangential elasticity* be not of sensible magnitude, the mass may be emphatically said to be *plastic*. This is the essential condition of what may with strict propriety be termed *plasticity*; it might also

be added that, as bodies are constituted in nature, the force required to produce the original displacement in plastic bodies will be small as compared with that required in solid bodies. *Viscosity* and *semifluidity* are terms which only express similar properties of bodies, but indicating that still smaller forces only are required to produce a given displacement in viscous or semifluid bodies than in plastic ones. The limiting case is that of *perfect fluidity*, in which both the forces of original displacement and those of restitution are indefinitely small. In these latter cases the tangential cohesion is necessarily small, and such also (as bodies are usually constituted) will be the normal cohesion. At the same time the power of resisting compression of volume may be very great, as in fact it is in nearly all masses not technically designated as *elastic masses*. In other words, the *normal* elasticity, with reference to pressure, may be of any magnitude, while the *tangential* elasticity equals zero.

It will be observed that I have here spoken of a body as held in a state of constraint by external forces, but without any kind of dislocation which should destroy its continuity or injure its structure. If, however, the external forces should be sufficiently increased, the structure of a vitreous or crystalline mass, or that of any mass possessing hardness and brittleness, will be destroyed by a pressure greater than its power of resistance can withstand; or the continuity of its mass will be destroyed by any normal tension greater than the normal cohesion, or, again, by any tangential tension greater than the tangential cohesion. The normal tension would then produce an open fissure; and the tangential tension would cause one particle of the mass to slide past another, but without producing any open discontinuity. On the contrary, in a properly plastic or viscous mass there is no definite structure for excessive pressure to destroy; there is no question as to the formation of open fissures; and the characteristic absence of *tangential* elasticity allows of any amount of change in the relative positions of the constituent particles of the mass without breach of its continuity.

It would of course be impossible to draw an exact and determinate line of demarcation between solidity and plasticity, but it is not therefore the less certain that there are bodies which do unequivocally possess the property of solidity, and others which do as unequivocally possess the property of plasticity, according to the definitions I have given of these terms. Solidity and plasticity with respect to numerous cases in nature thus become determinate properties of those aggregates of material particles which we call bodies. Ice, a vitreous or crystalline and brittle mass, which will neither bear any but the smallest extension without breaking, nor more than the smallest compression without being crushed, must be solid, and cannot be plastic, if we are to use those terms as significant of determinate properties of bodies.

3. The advocates of the Viscous Theory would not probably admit the necessity of the above rigorous definition of the term *viscous* in its application to glacial ice. But the defect of that theory has always been in the entire want of any accurate definition of that term. When such a definition was demanded, it was said that glacial ice must be viscous, because a glacier adapted itself to the inequalities of its valley as a viscous

mass would do. This was equivalent to saying that the mass was viscous because it moved in a particular manner, instead of asserting that the mass moved in that particular manner because it was viscous. Now this kind of inversion of the direct enunciation of the proposition is only admissible when there is no other physical cause, than the one assigned, to which it is conceivable that the observed phenomenon should be ascribed. Thus we may assert with perfect conviction, that gravity exists as a property of matter and acts according to a certain law, because the bodies of the solar system move as if such were the case; but the conclusiveness of this inductive proof of the proposition—that "gravity is a property of matter"—rests entirely on our conviction that matter has no other property by which we could equally account for the phenomena of the celestial motions. And so with regard to glaciers. If viscosity were the only conceivable property of ice by which we could possibly account for the observed motion of glaciers, then would the observed phenomena of that motion perfectly convince us of the existence of the property in question. But here the two cases entirely differ, inasmuch as there was no general conviction, nor even a decided probability at the time I allude to, that no physical property of ice could exist besides viscosity which might account for the observed phenomena of a glacier's motion; and at the present time it is proved that there *is* another property of ice by which those phenomena are perfectly accounted for, and the inductive proof of viscosity becomes altogether valueless. Moreover, in the case of universal gravitation, the inductive proof is the only possible one, whereas in glacial motion we are concerned with a property which, in whatever sense the definition of it may be regarded, must be as capable of being rendered patent by experiment in ice, if it exist, as in any other substance.

The answer, then, that was given to the question, what is viscosity? comprised no definition at all of that term. The viscous theory ignored the possibility of the molecular mobility of a glacial mass, united with the preservation of its continuity, being attributable to any other property than that which was designated as *viscosity*, but without giving any exact definition of the term. If it was meant to define by it the property which I have defined by the same term, the theory had a legitimate claim to be considered a *physical* theory, because it assigned a determinate physical property as the cause of certain observed phenomena. In this sense, however, I conceive that it would now be admitted to be entirely disproved by Dr. TYNDALL's experiments, in which the ice exhibits so clearly the property of solidity, and the absence of all indication of plasticity. The hypothesis of viscosity, I imagine, could only have been adopted in the first instance from the apparent absence of any other property of ice which might account equally well for the molecular mobility of the glacial mass.

4. But if the determinate property of viscosity, as I have defined it, be not recognized in ice, what, it will be asked, is really the idea which has been attached to the term plastic or viscous? The question, as I have already intimated, is difficult to answer. Perhaps the best way of doing so is to refer to the "Prefatory Note" to Principal FORBES's 'Occasional Papers' (p. xvi). He there intimates that the expressions "bruising

and re-attachment," and "incipient fissures re-united by time and cohesion," used by him in 1846, are to be regarded as having the same meaning as the expression "fracture and regelation," first introduced into the subject in 1857. Now there is no ambiguity whatever in this latter expression. "Fracture" means the breaking and splitting of the ice regarded as a brittle and crystalline *solid*, and could never be intended to have the slightest reference to viscosity. In fact the expression is altogether inapplicable to any body which can be called viscous, without what I should regard as a violation of scientific language. Still this, it may be said, may be only a want of strict accuracy of expression, rather than of accuracy of conception. But if a notion of cracking and breaking, so foreign to any idea of plasticity, should be admitted, it could not be said that a glacier moved as it is observed to move because it was plastic, but merely that it moved *as if* it were plastic. The true inference from the motion would have been that glacial ice possessed not necessarily real plasticity, a definite property of bodies, but a *quasi-plasticity*, which expresses no determinate property at all, but may consist with many different properties. It merely expresses, in fact, the power of the component elements of the mass of changing to a certain extent their relative positions. But this is not the peculiar property of ice; it is common, indeed, to all bodies exposed to disruptive forces which, as in the case of ice, the cohesive power is unable to withstand. The mass of any other substance, as well as that of a glacier, will then be broken into fragments sufficiently small to allow it to follow the impulses of the external forces acting on it. To say, therefore, that a glacier moves *as if* it were plastic is not to assign to ice any property peculiar to itself, and therefore does not properly constitute a *physical* theory of glacial motion at all.

5. But if we should pass over the difference between true plasticity and that which, as we have pointed out, is merely apparent, there would still remain the great difficulty which was only removed by the experiments of Mr. Faraday and Dr. Tyndall. Every one who believed ice to be a solid body, believed as a matter of necessity that a glacier must, on account of the external conditions to which it is subjected, be excessively broken and dislocated in the course of its motion. I was myself one of those who fell into the error of attributing too much influence to the larger and more visible disruptions of the mass; but the great difficulty was in the perfect subsequent reunion of portions which had thus been separated, whether by larger or smaller dislocations. And here it will necessarily be asked whether, in the expression above quoted, "*re-attachment*" and the "*re-union* by time and cohesion" of separated portions when again brought into contact, really mean the same thing as *regelation*? It can only be answered, I think, by saying that, whatever might be the intended meaning of those expressions, they failed to convey to the minds of others the most remote idea of regelation as a property of ice at a particular temperature. No better proof can be given of this than the general conviction which appeared to flash across the mind of every glacialist when he first heard of Dr. Tyndall's experiment, that the recognition of the property of instantaneous regelation was a well-marked and important discovery, which had at once completely

removed a great stumbling-block in glacial theory. In fact, the viscous theory assigns no physical cause for the reunion in question. All we could do, before the publication of those experiments, was to infer from the observed facts that ice did possess some property which facilitated the reunion of separate pieces in contact; but this was like the attempt to define viscosity by an appeal to the phenomena which that property was intended to explain.

6. An *imperfect plasticity* in ice has sometimes been spoken of. The fact is, all solid bodies might be said to have an imperfect plasticity, if we chose to admit this vagueness in scientific language, since all are capable of greater or less extension or compression. As to the apparent plasticity inferred from the motion of glacial masses, and arising from the crevicing of the ice, I have explained that it has no relation whatever to real plasticity. Such crevices are the necessary consequences of the external forces acting on the glacier, and are as essential to the theory of regelation as they are unconnected with any property of plasticity.

I proceed, as proposed in my introductory remarks, to explain the *sliding* of glaciers.

SECTION II.—*Sliding Motion of Glaciers along the bottoms of the Valleys containing them.*

7. The sliding motion of glaciers, as first suggested by DE SAUSSURE, seemed to involve some serious difficulties. The inclination of the surfaces along which some of the Alpine glaciers descend is so small (not exceeding, perhaps, in some cases 3° or 4°) as to furnish one very obvious objection; and another was, that if glaciers did thus move at all, it must be by an *accelerated* motion, whereas their real motion was an unaccelerated one. Both these objections were founded on an entirely erroneous conception of the nature of the forces called into action in the sliding of a glacier. They were considered to be analogous to the force of friction in the ordinary case of a body sliding down an inclined plane. But in this latter case the constitution of the sliding body, and of that on the surface of which it slides, is always assumed to be such that the surfaces in contact are not affected by the sliding movement, and then we have the experimental law that the friction is independent of the velocity. Consequently the motion is an *accelerated* one. But the condition just mentioned, respecting the surfaces in contact, will not be satisfied in the case of a glacier, assuming what I shall prove shortly, that its lower surface must necessarily have a temperature not lower than that of freezing, and must consequently be always on the point of disintegration by thawing. Ice then becomes very tender, and the cohesion of its particles at its lower surface becomes insufficient to prevent the descent of a mass of such an enormous weight as that of a glacier, even along planes of the smallest inclination. This was clearly illustrated by a simple experiment which I made some years ago, which also fully explained the unaccelerated motion of a sliding glacier. The details of this experiment will be found in the Cambridge Transactions for 1844*. It constitutes so fundamental a step in this subject, according to my own views of it, that I would beg permission to give here a brief description of it, and of the results to which it leads.

* They will also be found in the Philosophical Magazine for January 1845.

8. A mass of ice was placed on a flat rough slab of sandstone, so arranged that it could easily be placed at any proposed inclination to the horizon. When the inclination was about 20°, the ice descended with an accelerated motion as in ordinary cases, but at smaller inclinations it descended with a *slow uniform motion*, which, for inclinations not exceeding 9° or 10°, was, *cæteris paribus*, *proportional to the inclination*. The velocity was increased by an *increased weight* of the mass, the area in contact with the plane remaining the same. The motion was due to the melting of the ice in contact with the slab, for when the temperature of the air became below that of freezing, it entirely ceased.

The motion was sensible for inclinations little exceeding half a degree, and, doubtless, would also have been so for smaller inclinations. This shows how small a force was required to move the mass when its lower surface was in a state of disintegration. Let f be a retarding force applied to a mass whose weight $=W$, placed on a plane whose inclination is ι. Then will $W \sin \iota - f$ be the moving force along the plane; and since the mass will require only the smallest force to move it, a force f very nearly equal to $W \sin \iota$ will be necessary to hold the mass at rest. If f be removed, the ice will begin to move with a moving force nearly $= W \sin \iota$, the motion being permitted by the liquefaction of successive indefinitely thin layers of ice, but then it will be retarded by the solid mass coming in contact with the surface on which it slides. A melting of another indefinitely thin layer will then take place, and the above process will be repeated, the velocity increasing till the continuous action of the plane on the mass becomes equal to the weight resolved in the direction of the plane. During this time (probably too short to be estimated) the motion will be an accelerated one, but will thenceforward become uniform, the action of the plane becoming equal to the resolved part of the weight along it. The uniform velocity is, in fact, a *terminal* velocity, similar to that of a stone descending in water, when it soon approximates to a nearly uniform motion. The action of the inclined plane on the moving mass, like that of the resistance of the water on the stone, has this property—that, while it is incapable of exerting any but the smallest force to hold the body absolutely at rest, it exerts a retarding force upon it in uniform motion, equal to that of gravity. The objections above mentioned against the sliding of glaciers have arisen from an entire misconception of this kind of mechanical action.

9. At the period when the preceding experiment was published, I was disposed to think that the greater part of the observed motion of the surface of a glacier was due to the general motion, by sliding, of the whole mass, while it was contended by other glacialists that it was principally due to an excess of the velocity of the upper strata of the mass over that of its lower strata, due to a gradual change of form of the whole mass, and that there might in fact be no sliding movement at all. In recognizing that both these causes might be *veræ causæ**, I urged the necessity of deciding on their relative claims by actual observations, which should determine the velocities of the upper and lower surfaces of a glacier at some point where the lower one was accessible. Observa-

* Philosophical Magazine and Journal for February 1845.

tions for this purpose were made by Principal FORBES in 1846, at the bottom of the Glacier des Bois at Chamouni. He found that the velocity of a point on the surface, at the height of 143 feet above the bed of the glacier, was to that of a point 8 feet above the bed, in the ratio of nearly 16 : 10*, whence it follows that, if we divide the whole velocity of the surface into eight parts, five of them will be due to the motion of the bottom of the glacier, and three to that change of form of the mass by virtue of which its higher move faster than its lower portions. Dr. TYNDALL has also made similar observations on the flank of the Mer de Glace†, from which it appears that the motion of the upper was there rather more than twice that of the lower surface. These observations may or may not determine approximately the average ratio between the velocities of the upper and lower surfaces of a glacier; but they leave no doubt as to the fact of the sliding movement. Again, it is observed that existing glacial valleys, and those which are believed to have been such in former times, always indicate, by their smoothed and striated rocks, the sliding movements of the glaciers they formerly contained. In fact, few glacialists at present, I imagine, will doubt the existence of this sliding motion, or that it forms a considerable portion of the whole motion of a glacier; and I believe that the experiments above described afford an adequate explanation of the cause and character of that motion. I insist on this more particularly because the explanation has been singularly ignored and misunderstood. The non-applicability of the experiments has been asserted, because the sliding mass was not obstructed in its motion by lateral obstacles, like a glacier, whereas, in fact, they had no concern with lateral obstacles, being merely intended to explain the action of the bed of the valley on the superincumbent glacier. The irregularity of the sides introduces, as we shall see very shortly, no difficulty or ambiguity into my views of the subject. I may also state that, several years after my experiments and his own observation above stated were published, Principal FORBES repeats his objection of the difficulty of conceiving the possibility of the motion of sliding glaciers being unaccelerated, whereas every one now acknowledges that they do slide, and knows that their motion is unaccelerated‡. M. AGASSIZ, on the contrary, after repeating the experiments, allows that the results remove the great difficulties of admitting the sliding motion of glaciers§. This kind of motion, as we have seen, depends very much on the temperature of the lower surface of the glacier being always equal to the freezing-temperature. That such must always be the case I proceed to show. All observations indicate that it is so; but still, since few direct observations can be made on this point, it may be well to show that it follows from the temperature of the earth, and the nature and conductivity of ice, that the temperature of the lower surface of a glacier must be that above mentioned.

* Occasional Papers, p. 175. † Glaciers of the Alps, p. 289.

‡ "The main objection, however, is this, that a sliding motion of the kind supposed, if it commence must be accelerated by gravity, and the glacier must slide from its bed in an avalanche. The small slope of most glacier-valleys, and the extreme irregularity of their bounding walls, are also great objections to the hypothesis."—Occasional Papers; also published in 1855 in the 'Encyclopædia Britannica.'

§ Système Glaciaire, p. 568.

10. *Interior Temperature of Glaciers.*—There are two obvious causes by which the temperature in the interior of a glacier may be affected—(1) conduction of heat from the superficies of the mass according to the ordinary laws of conduction through solid bodies, and (2) infiltration of water from the upper surface. We may consider separately the operation of these causes, with the view of determining whether the lower surface of the mass is permanently at the temperature of freezing, as it must be to render the preceding experiments strictly applicable to account for the continuous and unaccelerated motion of the glacier. To investigate the effect of the first cause, let us conceive the whole surface of the earth covered with a superficial crust of ice. The temperature of this crust will be subject to periodical annual variations to a certain depth, which will depend on the annual variations of the superficial layer of the icy crust, and the conductivity of the ice. It may be considered, for our immediate purpose, sensibly the same as the temperature of the glacier itself, at all points where the glacier and our imaginary crust of ice coincide. Now the surperficial changes of temperature in the crust of ice subject to conditions similar to those of a glacier, would be much less than those which the actual rocky crust of the earth experiences; for the temperature of the ice could never rise above 32° Fahr. in the hottest summer, nor in the coldest winter could it probably fall many degrees below that temperature, on account of the covering of snow like that which on all glaciers protects their outer surface against the effect of low winter temperature. Again, the depth through which these oscillations of temperature would be perceptible, would, *cæteris paribus*, be comparatively small if the conductive power of the mass should be so. I am not aware of any experimental determination of the value of this power for ice; but that substance is known to be a very bad conductor, and probably worse than the average of the rocks which form the outer crust of the earth. For both these reasons, then, the depth of oscillatory annual temperature would be much smaller than it is found to be within the actual crust of the globe, under the same external climatal conditions. Now in the earth's crust, and in our own latitudes, this depth may be approximately estimated at 70 or 80 feet, according to the nature of the upper strata. I should therefore deem it probable that the variations of external temperature in a crust of ice like that above supposed, or therefore in an ordinary glacier, would not exceed at most perhaps some 30 feet.

Again, let us consider the probable *mean* annual superficial temperature of our hypothetical icy crust, or of a glacier of ordinary dimensions. The actual temperature could never rise, as above remarked, above 32° Fahr., and would never sink many degrees below that temperature. M. Agassiz has left us the only reliable observations on this subject*. He buried a self-registering thermometer in the glacier of the Aar, at the depth of 2·1 metres. It was taken up two years afterwards, and was found to have registered a minimum temperature of $-2°{\cdot}1$ (C.) $=28°{\cdot}22$ (Fahr.). Thus the mean temperature for the winter was probably not less than 30° (Fahr.), and that for the

* Système Glaciaire, p. 425.

whole year might perhaps not much fall short of 31° (Fahr.)*. If the conductive power of ice were equal to that of the earth's crust, the mean temperature would increase 1° (Fahr.) in descending some 60 or 70 feet; and therefore, on account of the smaller conductivity of ice, it would probably, in the case of a glacier, rise to 32° (Fahr.) at a depth of some 30 or 40 feet. This would hold, it should be observed, on the supposition that the substance below this depth should be capable, like the matter of the earth's crust, of taking any temperature higher than 32° (Fahr.). This higher temperature would be acquired, as in the actual case of the earth, by the flow of heat from the earth's interior. But in the case of a glacier this heat will be expended in melting the lower stratum of ice instead of communicating a higher temperature to the whole mass. Consequently, if the thickness of the glacier exceed some 30 or 40 feet (a depth at which, as above shown, the temperature will be invariable), the temperature of the lower surface will be constant and equal to 32° (Fahr.).

The temperature at any proposed point (P) of the interior of a glacier, at a depth greater than that estimated above at some 30 or 40 feet, will always be constant and less than 32° (Fahr.), provided the mean annual temperature of the external surface of the glacier be so. To find this constant temperature at P, take for the temperature of the upper surface its mean annual temperature. Let it $=T^\circ$ (Fahr.). Also let a=thickness of the glacier, x=distance, from the upper surface, of the proposed point, and t its required temperature. Then shall we have, according to the laws of conduction of heat,

$$\frac{t-T^\circ}{32^\circ-T^\circ}=\frac{x}{a},$$

the difference of temperatures, as is well known, being approximately proportional to the distances from the upper surface. Hence

$$t=T^\circ+\frac{x}{a}(32^\circ-T^\circ),$$

which shows that t must always be greater than T°; it must also be less than 32° (Fahr.), and must therefore lie between those quantities. Consequently, since $32^\circ-T^\circ$ is small for the Alpine glaciers, their internal temperature must be nearly uniform, but always a little below 32° (Fahr.), supposing it to depend only on the process of conduction.

But the process of infiltration will tend to raise the internal temperature more nearly to 32° Fahr.; for since the infiltrated water will have that temperature, it will constantly tend to heighten the temperature of the mass through which it passes till it rise to 32° (Fahr.), and never to lower it. This water must thus bring to the glacier (a mass of lower temperature than itself) a continual accession of heat, which it can only lose again by conduction through the upper surface during the winter; and this loss will be restricted to that small depth beyond which the annual variations of temperature cannot extend. For all points at greater depth infiltration must ultimately raise the temperature to 32° (Fahr.).

* M. Agassiz states that the temperature given by his experiment might possibly be somewhat too high. There is no probability, however, that the error would be sufficient to affect the reasoning in the text.

Hence, then, considering the combined operation of conduction and infiltration, it appears that, to the depth of perhaps 30 feet, the *interior* temperature of a glacier will be 32° (Fahr.) during the summer portion of the year, but will be rather lower than 32° (Fahr.) during the winter. For all deeper parts of the glacier it will be invariably equal to 32° (Fahr.).

These results are in exact accordance with the careful observations made by M. Agassiz, which have already been partially referred to. Besides the winter observations above mentioned, he also observed the temperatures in the month of July, at depths of from 3 to 5 metres, at 30, and at 60 metres. These temperatures were all exactly 32° (Fahr.) during the fortnight they were observed, with the exception of one or two very small and manifestly accidental variations in the more superficial observations.

11. It follows from the preceding articles that the temperature at the lower surface must always be the freezing-temperature, *i. e.* the ice there must be in that state in which the mutual cohesion of its constituent particles is less than in any other state. It does not follow that the glacier would not slide if the temperature of its lower surface were less than 32° (Fahr.); but that temperature is the most favourable for the motion of the glacier, because the most favourable to the disintegration of its lower surface, and the immediate conversion of the ice which forms it into water. It should be remembered, too, that it was one of the results of my experiment, that, *cæteris paribus*, the motion was increased by increasing the weight of the mass; *i. e.*, the cohesive power of the ice at the bottom of the glacier will be the more rapidly overcome by increasing the depth of the mass, the area of its base being unchanged. Consequently the tendency of a glacier to descend down its bed would be indefinitely greater, *cæteris paribus*, than that of our experimental lump of ice down its plane. It is this enormously increased tendency that enables the mass of a glacier to overcome the resistance arising from the inequalities of the sides and bottom of its valley. We shall explain in the sequel the prodigious force which may thus be exerted, and the corresponding internal tensions which would thus be produced by it. These tensions overcome the cohesion of the mass, the ice breaks, and the glacier obtains more freedom of motion than it could have in its state of greater compactness and continuity. The tendency to the sliding motion we are considering will manifestly be greater in the axial than in the marginal parts of the mass. It is there, especially, that the depth must be the greatest, and the distance from opposing lateral objects is likewise greatest; and, it may be added, the subglacial currents, by which the sliding will undoubtedly be more or less facilitated, will be generally greatest along the central parts of the valley.

Hence, then, it follows that, so far as the motion of a glacier depends on the *sliding* we have been considering, the velocity of its axial portions will generally be considerably greater than that of its marginal portions. This constitutes the most distinctive and important character of the observed motion of a glacier.

Still, though the sliding motion was perfectly consistent with this observed general character of glacial motion, it was not sufficient to account for several striking pheno-

mena attendant upon it. The formation of crevasses was a necessary consequence of the forces acting on the glacier, and the conditions to which it was subjected; but no reason was thus assigned why such crevasses should be obliterated again, as they were frequently observed to be, and the continuity of the mass perfectly restored. Moreover, it became evident from more accurate and detailed observation, that the continuity of many parts of the general mass was preserved in a degree apparently inconsistent with the change of form to which a mass so crystalline and brittle as glacial ice did manifestly submit. It was to meet this difficulty that Principal FORBES was led to the hypothesis of the *viscosity* or *plasticity* of glacial ice. I have already explained my objection to the vagueness with which these terms appear to me to have been used, and to the total want of all experimental proof of any property in ice which could be so designated with accuracy, or with a due regard to the propriety of scientific language. Difficulties of this kind always remained on the minds of certain glacialists, till the experiments of Mr. FARADAY and Dr. TYNDALL at once explained to us that *regelation*, and not *viscosity*, was the real property of ice required for the completion of our general theory of glacial motion. This property of regelation belongs essentially to *solid* bodies, and in treating glacial masses as bodies possessing the property of regelation, we must necessarily treat them as *solid*. As such I consider them in the following investigations, the object of which is to ascertain, as far as we are able, the internal pressures and tensions to which glaciers are subjected, and the phenomena which may result from them, more especially those connected with the veined structure of glacial ice, and the formation of crevasses.

12. Before I proceed to these investigations, I would here remark that the importance of a distinct conception of the properties indicated by the terms viscosity or plasticity on the one hand, and solidity on the other, will be at once apparent if we consider the difference between the mechanical problems presented to us in the motion of glaciers, according as we conceive them to be typified by a viscous or solid mass. In the first case we have to determine the continuous motion of a mass the component particles of which move with different velocities, but without destroying its continuity. The most simple, and the limiting case, would be that in which the tangential action of contiguous particles on each other should vanish. The mass would then become a fluid mass. But even in this case we can do little by accurate mathematical investigation, and still less in the case in which the mass is viscous. Consequently, the objection against any attempt at a mathematical solution of the problem of glacial motion, founded on our ignorance of the motions of viscous masses, is perfectly valid, so long as we treat glacial ice as viscous according to our definition of that term. But this same objection has been urged against all attempts to apply accurate mathematical processes to the problem, in its complete or partial solution, under the supposition of ice having the property of solidity. The complete solution of the problem would undoubtedly be far more difficult for a solid than for a viscous mass; for it would involve conditions depending on innumerable discontinuities in the mass, resulting from its motion. All that can be attempted is a

partial solution of the problem, in which the dynamical difficulties are evaded. It has been already explained that when a solid body is acted on by external forces, it generally becomes distorted in form and changed in volume. If the forces be insufficient to overcome the cohesion of the mass and to dislocate it, they will of course continue to maintain the body in its state of constraint and distortion, and thus to produce, at different points of its interior, pressures and tensions varying both in direction and intensity. The immediate object of the first part of the investigations contained in the following pages, is the proof of certain propositions respecting these internal pressures and tensions, and the phenomena resulting from them. The problem thus considered is not a dynamical, but a statical one, in which certain results are attainable with the same accuracy as in the simplest mechanical problems; and such are the only results with which we are directly concerned in our present researches. If the distorting forces be sufficiently increased, the mass will be torn or crushed, as already stated, and will then move according to the new conditions imposed upon it in its state of dislocation. This constitutes the dynamical part of the problem, but, it must be recollected, it does not enter at all into the mathematical part of our own investigations. I have thought it necessary to point out this distinction, lest any vague objection resting on an imperfect or erroneous conception of the problem before us should exercise an undue influence on the mind of the reader.

Section III.—*On the Pressures and Tensions at any point of a Solid Mass held in a position of constraint by external forces.*

13. We may now proceed to the consideration of the general problem, the object of which is to investigate the nature of the internal pressures and tensions at any proposed point of a solid mass subjected to the action of impressed forces which slightly distort it from the form it would assume when acted on by no external forces at all. It will be recollected that these forces are supposed insufficient to destroy the continuity of the mass. They maintain it in its distorted form, and must therefore be in *equilibrium* with the internal forces arising from the cohesive power of the mass.

To explain the nature of the distortion produced in any small element of the mass, let us denote by s the area of an indefinitely small plane surface passing through any point (P). Generally there will be an action between the particles (M) on one side of our small plane, and those (M′) on the opposite side. Since s is indefinitely small, we may represent by f the whole action of M on M′, and suppose its direction to make an angle δ with the normal to the plane s. Then will

$$f\cos\delta \text{ and } f\sin\delta$$

be the normal and tangential actions respectively of M on M′; and

$$-f\cos\delta \text{ and } -f\sin\delta$$

will be the corresponding actions of M′ on M. If the normal force be a *pressure*, it will

only tend to preserve the particles on opposite sides of s in contact, but if it be a *tension*, it will tend to separate those particles by motions parallel to the normal. Also the tangential forces $f \sin \delta$ and $-f \sin \delta$ will always tend to separate two particles on opposite sides of s and in contact, by making them move in opposite directions parallel to the plane. If we conceive s to revolve about P as a fixed point, and thus to assume all possible angular positions, the forces $f \cos \delta$ and $f \sin \delta$ will vary with the angular position of the plane, in certain positions of which they will assume their maximum and minimum values. The determination of these positions is one immediate object of the problem, with the view of determining the effect of the distorting forces on the form of each element of the mass, and thence, if the problem were completely soluble, the distortion of the whole mass. But before proceeding further, we may explain more explicitly what will be the kind of distortion to which every element of any solid body will be subjected under the action of distorting forces. Let us take a small rectangular parallelopiped as the element of the body while unconstrained by such forces. The normal forces acting on opposite sides of the element will manifestly form three pairs of equal* and opposite forces, each force of each pair acting in a direction opposite to the other force of that same pair, and thus producing compression or extension of the element according to the directions in which they act. Again, it is manifest, from what has been said respecting the small plane s, that the tangential force on any one side of the elementary parallelopiped will be equal to that on the opposite side, but will act in the opposite direction, thus tending to *twist* the element from its original rectangular form into an oblique-angled parallelopiped. Hence the primitive undistorted element will be compressed or extended according to circumstances, and will always (unless the forces acting on it be entirely normal) be twisted so as to destroy its rectangularity. In the final application of the results obtained from this our typical problem, we shall have to deduce the manner in which the continuity of the glacial mass will be destroyed when the power of resistance of the ice is no longer sufficient to equilibrate the distorting forces acting on it, and also to consider the phenomena which may result from such breach of continuity.

With respect to the solution of our abstract problem, I have little to add to that which I gave in the Transactions of the Cambridge Philosophical Society for the year 1847, and I might be content merely to refer to that solution for the results. In doing so, however, it would be necessary to give a somewhat complicated notation, and certain explanations in such detail that the space thus occupied would not differ materially from that required for the mathematical analysis of the first part of the general problem. By giving this analysis here, considerable trouble of reference will be avoided. I would request permission, therefore, to repeat a part of what appeared in the Transactions above referred to. The quotation includes the following articles, from the 14th to the 17th inclusive:—

* Omitting small quantities of a certain order, which it is not necessary in this general explanation to take into account.

14. "Taking any point (P) of the mass, let it be made the origin of coordinates xyz. Let the small plane s be conceived as above to pass through P, and let the forces upon it when in the positions specified below be denoted as follows, all being referred to a unit of surface.

"(1) When a perpendicular to the plane coincides with the axis of x, let

$$\text{The } \textit{normal force} = \mathrm{A}; \text{ the } \textit{tangential force} = \begin{cases} \mathrm{B}' \text{ parallel to } y, \\ \mathrm{C}' \quad\quad\ \text{,,} \quad\ z. \end{cases}$$

"(2) When a perpendicular to the plane coincides with the axis of y, let

$$\text{The } \textit{normal force} = \mathrm{B}; \text{ the } \textit{tangential force} = \begin{cases} \mathrm{C}'' \text{ parallel to } z, \\ \mathrm{A}' \quad\quad\ \text{,,} \quad\ x. \end{cases}$$

"(3) When a perpendicular to the plane coincides with the axis of z, let

$$\text{The } \textit{normal force} = \mathrm{C}; \text{ the } \textit{tangential force} = \begin{cases} \mathrm{A}'' \text{ parallel to } x, \\ \mathrm{B}'' \quad\quad\ \text{,,} \quad\ y. \end{cases}$$

"Between the six accented quantities there are three essential relations, which are easily found. On the three coordinate axes at P, construct an indefinitely small parallelopiped whose edges are δx, δy, δz. The six equations of equilibrium of this element will express the conditions that the sums of all the resolved parts of the forces parallel to the coordinate axes shall respectively be equal to zero; and that the moments of the forces with reference to these axes shall also severally be equal to zero. Let us take the three latter conditions, lines through the centre of gravity of the element and parallel to the coordinate axes being taken for the axes of the component couples. The tangential force parallel to the axis of x on the side $\delta x.\delta z$ being A', that on the opposite side will be $-\left(\mathrm{A}'+\frac{d\mathrm{A}'}{dy}.\delta y\right)$; and the couple resulting from these forces about the axis parallel to z, will be

$$\mathrm{A}'\delta x\delta z.\frac{\delta y}{2}+\left(\mathrm{A}'+\frac{d\mathrm{A}'}{dy}\delta y\right)\delta x\delta z.\frac{\delta y}{2};$$

or, omitting small terms of the fourth order,

$$\mathrm{A}'\delta x\delta y\delta z.$$

"Similarly, the couple arising from the forces B' and $\mathrm{B}'+\frac{d\mathrm{B}'}{dx}\delta x$ about the same axis parallel to z, will be

$$-\mathrm{B}'\delta x\delta y\delta z.$$

"Also the moments of the normal forces A, B, C, with reference to the above-mentioned axes, will be zero, always omitting small quantities of the fourth order. Consequently the whole moment of the forces on the parallelopiped with reference to the axis parallel to that of z, will be

$$(\mathrm{A}'-\mathrm{B}')\delta x\delta y\delta z,$$

which must = zero by the conditions of equilibrium; and therefore

$$\mathrm{A}'=\mathrm{B}'.$$

In exactly the same way we find, by taking the moments with reference to the axes parallel respectively to those of y and x,

$$A''=C',$$
$$B''=C''.$$

By means of these three relations the six accented quantities are reduced to three independent quantities.

15. "Let us now conceive a plane to meet the three coordinate planes so as to form with them a tetrahedron, whose vertex is at the origin P. Suppose the exterior normals to the three faces formed by the coordinate planes to point respectively towards the positive directions of x, y, and z; and let α, β, γ be the angles which the normal to the base of the tetrahedron makes with the coordinate axes of x, y, z. Also, let s denote the area of the base, and s', s'', s''' the areas of the sides of the tetrahedron perpendicular respectively to the axes of x, y, z, all these quantities being indefinitely small.

"Again, let ps denote the whole resultant force on s, and let λ, μ, ν be the angles which its direction makes with lines parallel to the axes x, y, z, this direction being exterior to the tetrahedron. Then in order that the tetrahedron may be in equilibrium, we must have

$$ps.\cos\lambda = As' + A's'' + A''s''',$$
$$ps.\cos\mu = Bs'' + B's' + B''s''',$$
$$ps.\cos\nu = Cs''' + C's' + C''s'';$$

but

$$\frac{s'}{s}=\cos\alpha,\quad \frac{s''}{s}=\cos\beta,\quad \frac{s'''}{s}=\cos\gamma;$$

making these substitutions, and also putting

$$B''=C''=D,$$
$$A''=C'=E,$$
$$A'=B'=F,$$

we shall have

$$\left.\begin{aligned} p.\cos\lambda &= A\cos\alpha + F\cos\beta + E\cos\gamma,\\ p.\cos\mu &= B\cos\beta + F\cos\alpha + D\cos\gamma,\\ p.\cos\nu &= C\cos\gamma + E\cos\alpha + D\cos\beta,\end{aligned}\right\} \quad \ldots\ldots\ldots \quad (a.),$$

formulæ in which the notation agrees with that of M. Cauchy*.

16. "If δ denote the angle between the direction of p and the normal to s, we shall have $p.\cos\delta$ for the whole *normal* force acting on the area s in a direction exterior to the tetrahedron, and $p.\sin\delta$ the whole *tangential* force acting on the same area. Our first object will be to determine α, β, and γ, or the position of the base s of the tetrahedron, so that the normal action upon it, $p\cos\delta$, shall be a maximum. We shall afterwards have a similar investigation with reference to the tangential force $p.\sin\delta$.

* Exercices de Mathématiques, vol. ii. p. 48.

" We have

$$\cos\delta = \cos\lambda\cos\alpha + \cos\mu\cos\beta + \cos\nu\cos\gamma,$$

whence we immediately obtain

$$p\cos\delta = A\cos^2\alpha + B\cos^2\beta + C\cos^2\gamma + 2D\cos\beta\cos\gamma + 2E\cos\alpha\cos\gamma + 2F\cos\alpha\cos\beta; \quad (1.)$$

and since

$$\cos^2\alpha + \cos^2\beta + \cos^2\gamma = 1, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2.)$$

we have (L being an arbitrary multiplier),

$$(A+L)\cos^2\alpha + (B+L)\cos^2\beta + (C+L)\cos^2\gamma + 2D\cos\beta\cos\gamma + 2E\cos\alpha\cos\gamma + 2F\cos\alpha\cos\beta = max.$$

Hence

$$\left.\begin{aligned} \{(A+L)\cos\alpha + E\cos\gamma + F\cos\beta\}\sin\alpha &= 0, \\ \{(B+L)\cos\beta + D\cos\gamma + F\cos\alpha\}\sin\beta &= 0, \\ \{(C+L)\cos\gamma + D\cos\beta + E\cos\alpha\}\sin\gamma &= 0. \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (b.)$$

" To satisfy these equations together with (2.), we must equate the first brackets to zero. We thus have four equations from which L may be eliminated, and α, β, and γ determined.

" If we multiply the first factors on the left-hand sides of equations (*b.*) by cos α, cos β, cos γ respectively, and add them together, we have, by virtue of equations (*a.*),

$$L = -p\cos\delta;$$

and substituting for L in equations (*b.*), we have

$$\begin{aligned} p\cos\delta\cos\alpha &= A\cos\alpha + F\cos\beta + E\cos\gamma \\ &= p\cos\lambda \end{aligned}$$

by the first of equations (*a.*); and therefore

$$\cos\delta\cos\alpha = \cos\lambda,$$

and similarly

$$\begin{aligned} \cos\delta\cos\beta &= \cos\mu, \\ \cos\delta\cos\gamma &= \cos\nu, \end{aligned}$$

whence

$$\begin{aligned} \cos^2\delta &= 1 \\ \delta &= 0, \end{aligned}$$

which shows that when the resultant force p is a maximum or minimum, its direction coincides with that of the normal to the plane s. Consequently, also, the tangential force, p sin δ, then becomes = zero.

" This value of δ gives $L = -p$; and substituting for L in equations (*b.*), we have

$$\left.\begin{aligned} (A-p)\cos\alpha + F\cos\beta + E\cos\gamma &= 0, \\ F\cos\alpha + (B-p)\cos\beta + D\cos\gamma &= 0, \\ E\cos\alpha + D\cos\beta + (C-p)\cos\gamma &= 0; \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (c.)$$

and eliminating cos α, cos β, and cos γ by cross multiplication, we obtain

$$(A-p)(B-p)(C-p) - D^2(A-p) - E^2(B-p) - F^2(C-p) + 2DEF = 0. \quad . \quad . \quad (3.)$$

"If we take the three values of p deducible from this equation, and substitute them successively in equations ($c.$), those equations combined with (2.) will give three distinct systems of values for $\cos\alpha$, $\cos\beta$, and $\cos\gamma$, belonging (as is well known) to three lines perpendicular to each other.

17. "Hence it follows that there is at every point (P) of a continuous solid mass under extension or compression, a system of three rectangular axes, such that if the small plane s at P be so placed that its normal shall coincide with one of those axes, the whole resultant action on s shall be *normal* to it, the tangential action upon it being then equal to zero. These three axes are called *the axes of principal pressure or tension* with reference to the point P.

"Of the three values of p in these directions, though they all satisfy the conditions of maximum or minimum, one is a maximum, another a minimum, and the third is neither an absolute maximum nor an absolute minimum. This is best explained, perhaps, by converting equation (1.), as Cauchy has done, into an equation to a surface of the second order, by putting

$$p\cos\delta=\frac{1}{r^2},\quad r\cos\alpha=x,\quad r\cos\beta=y,\quad r\cos\gamma=z.$$

The inverse of the square of any radius vector will be a measure of the normal action through P perpendicular to this radius vector, the axes of this surface of the second order coinciding with the axes of principal tension or pressure. Of the three principal axes of this surface, the directions of the greatest and least will manifestly coincide with those of minimum and maximum tension; but though the tension in the direction of the mean axis of the above surface satisfies the two conditions $\frac{d.p\cos\delta}{d\alpha}=0$ and $\frac{d.p\cos\delta}{d\beta}=0$, it satisfies the one because it is maximum with respect to α, and a minimum with respect to β, or the converse, as the mean axis of an ellipsoid is a maximum in one principal section of the surface, and a minimum in the other."

18. The object of the second part of this investigation* is to determine the angular positions of the small plane (s) passing through P, so that the tangential force acting upon it shall be greatest, *i. e.* that $p\sin\delta$ may be a maximum. Our formulæ will be much simplified by taking the axes of principal tension or pressure as the coordinate axes. In this case we shall have

$$D=0,\quad E=0,\quad F=0;$$

and if A_1, B_1, C_1 now represent the principal tensions at the proposed point, and α_1, β_1, γ_1 be the values of α, β, γ referred to these new axes, equations ($a.$) will give

$$p^2=A_1^2\cos^2\alpha_1+B_1^2\cos^2\beta_1+C_1^2\cos^2\gamma_1,$$

and equation (1.) gives

$$p\,.\cos\delta=A_1\cos^2\alpha_1+B_1\cos^2\beta_1+C_1\cos^2\gamma_1.$$

* A solution of the problem above investigated was also given by M. Cauchy, in his 'Exercices de Mathématiques' (vol. ii. p. 48). The solution of the problem in this second part of the investigation has only been given, I believe, by myself.

Hence we have (if $p \sin \delta = T$)

$$T^2 = p^2 \sin^2 \delta = A_1^2 \cos^2 \alpha_1 + B_1^2 \cos^2 \beta_1 + C_1^2 \cos^2 \gamma_1 - (A_1 \cos^2 \alpha_1 + B_1 \cos^2 \beta_1 + C_1 \cos^2 \gamma_1)^2,$$

which is to be a maximum subject to the condition

$$\cos^2 \alpha_1 + \cos^2 \beta_1 + \cos^2 \gamma_1 = 1.$$

The solution of this problem is longer and more complicated than that of the problem solved in the first part of the investigation. It will here be sufficient for my purpose to state the results, and, for the analytical solution, to refer the reader to the volume of the Cambridge Transactions above quoted. The results are as follows:—

α_1, β_1, and γ_1 being the angles which define the position of the small plane s (art. 13), the analytical conditions for the tangential force (T, or $p \sin \delta$) upon it being a maximum or minimum, are satisfied by the following three systems of contemporaneous values:—

$$\left.\begin{array}{lll} (1) & \alpha_1 = 90^\circ, & \beta_1 = \gamma_1 = \pm 45^\circ, \\ (2) & \beta_1 = 90, & \gamma_1 = \alpha_1 = \pm 45, \\ (3) & \gamma_1 = 90, & \alpha_1 = \beta_1 = \pm 45; \end{array}\right\} \quad \ldots\ldots\ldots \quad (d.)$$

and if T_1, T_2, and T_3 be the values of T corresponding respectively to these systems of values of α_1, β_1, and γ_1, we have

$$T_1^2 = \tfrac{1}{4}(B_1 - C_1)^2, \quad T_2^2 = \tfrac{1}{4}(A_1 - C_1)^2, \quad T_3^2 = \tfrac{1}{4}(A_1 - B_1)^2.$$

If A_1, B_1, C_1 be taken, as they always may be, in order of magnitude, T_2 will manifestly be the greatest of these values of T. It is in fact, as shown in the memoir referred to, the only value which satisfies all the conditions of a maximum. The corresponding values of α_1, β_1, and γ_1, which determine the corresponding position of the plane s, are those given by the second system of ($d.$). Now β_1 is the angle between the normal to s and the axis of y; and since it is here $= 90°$, the normal to s must lie in the plane of xz, and the plane s itself must pass through the axis of y. Moreover, since the corresponding values of α_1 and γ_1 are each $\pm 45°$, this plane may have two positions, in both of which it bisects the angle between the coordinate planes of xy and yz, these positions being on opposite sides of the plane of yz. These considerations, however, only determine the position of the plane in which the maximum tangential force (T_2) acts; they do not determine the linear direction of the force in that plane. It is easily shown that it is perpendicular to the axis of y*. Since we have here $D = 0$, $E = 0$, and $F = 0$ (art. 15), we have from equations ($a.$),

$$p \cos \lambda = A_1 \cos \alpha_1,$$
$$p \cos \mu = B_1 \cos \beta_1,$$
$$p \cos \nu = C_1 \cos \gamma_1,$$

p being the whole resultant force on the small plane s, referred to a unit of surface, and

* No proof of this is given in my memoir above referred to in the Cambridge Transactions.

λ, μ, ν being the angles which its direction makes with our present coordinate axes of x, y, z respectively. Hence

$$p^2 = A_1^2 \cos^2 \alpha_1 + B_1^2 \cos^2 \beta_1 + C_1 \cos^2 \gamma_1,$$

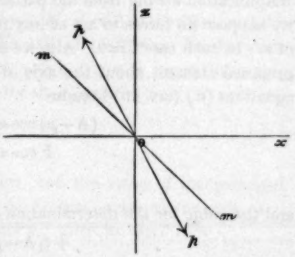
$$\cos \lambda = \frac{A_1 \cos \alpha_1}{\sqrt{A_1^2 \cos^2 \alpha_1 + B_1^2 \cos^2 \beta_1 + C_1^2 \cos^2 \gamma_1}},$$

$$\cos \mu = \frac{B_1 \cos \beta_1}{\sqrt{A_1^2 \cos^2 \alpha_1 + B_1^2 \cos^2 \beta_1 + C_1^2 \cos^2 \gamma_1}},$$

$$\cos \nu = \frac{C_1 \cos \gamma_1}{\sqrt{A_1^2 \cos^2 \alpha_1 + B_1^2 \cos^2 \beta_1 + C_1^2 \cos^2 \gamma_1}}.$$

But $\beta_1 = 90°$ in the case before us, and therefore μ must $= 90°$, *i. e.* the direction of the *whole resultant force* (p) on the small plane s must be perpendicular to the axis of y, and must lie in the plane of xz. Thus, the plane of the paper representing that of xz (fig. 1), the direction Op in that plane may represent the direction of p; and if Om bisect the angle between the coordinate axes x and z, that line will be the trace of a plane on xz coinciding with the plane of s, and therefore perpendicular to that of xz. Consequently, if we resolve the whole force p normally and tangentially with reference to the plane s, the tangential part will evidently coincide with Om. But, from the particular values of α_1, β_1, and γ_1, this tangential force must necessarily be the *maximum* tangential force T_s. Consequently, if we call the axis of y the *axis of mean principal tension or pressure*, the direction of the maximum tangential force (T_s) will be perpendicular to this mean axis, and will bisect the angle between the other two axes of principal tension.

Fig. 1.



19. Hence, in our first problem, the equations (2.) and (*c.*) determine α, β, γ, and p. The cubic for finding p, which is deduced from them, shows that there are three values of that quantity, the three principal tensions, whose directions are defined by corresponding values of α, β, and γ, and which are at right angles to each other. These quantities being known, the value of T_s, the maximum tangential force at the proposed point, and the direction in which it acts, are immediately determinable from the results of the second part of the problem as given above. To do this we must first determine the three systems of values of α, β, and γ which have been denoted by α_1, β_1, and γ_1, and which determine the positions of the axes of principal tension; and also the values of the three principal tensions which have been above denoted by A_1, B_1, and C_1. For the greater simplicity we then take these axes of principal tension for those of x, y, and z. If A_1, B_1, and C_1 be in order of algebraical magnitude, the axis of y will be the mean axis. If A_1 be a pressure and therefore negative, the proper order will be B_1, C_1, $-A_1$.

and the axis of z will become the mean axis. Other cases must be treated in a similar manner, always preserving the order of algebraical magnitudes for determining the mean axis. The line of greatest tangential action is always perpendicular to it, and bisects the angle between the other two axes of maximum and minimum tension. In determining the magnitude T_2, we must take the same precaution, in arranging the principal pressures in their proper order of magnitude, to determine which are algebraically the greatest and least. Thus in the above case, where the order is B_1, C_1, $-A_1$, we have $T_2=\frac{1}{2}(B_1+A_1)$. We may remark that the sign of T_2 is of no importance in any application we are contemplating of these formulæ.

20. *Solution to a First Approximation.*—The complete solution of the preceding equations cannot be generally obtained. For their practical application they must be solved by approximation, when the approximate solution may be sufficient. The most important case is one in which the problem can be completely solved in consequence of its simplification arising from the particular conditions assumed. The case is that in which we suppose no forces to act at any point parallel to one of the coordinate axes, as that of z. In such case $C=0$. Also we assume the absence of any couple tending to twist a proposed element about the axis of x, or that of y, *i. e.* $D=0$, and $E=0$. Hence the equations (*c.*) (art. 16) become

$$\left.\begin{aligned}(A-p)\cos\alpha+F\cos\beta=0,\\ F\cos\alpha+(B-p)\cos\beta=0,\\ (\ -p)\cos\gamma=0;\end{aligned}\right\} \quad \ldots\ldots\ldots \quad (c'.)$$

and the cubic for the determination of p becomes

$$+\{(A-p)(B-p)F^2\}p=0.$$

This last equation gives for the value of p,

$$p=\tfrac{1}{2}\{A+B\pm\sqrt{(A-B)^2+4F^2}\},$$
$$p=0.$$

Or putting $(A-B)^2+4F^2=M^2$,

$$\left.\begin{aligned}p_1&=\tfrac{1}{2}\{A+B+M\},\\ p_2&=\tfrac{1}{2}\{A+B-M\},\\ p_3&=0.\end{aligned}\right\} \quad \ldots\ldots\ldots \quad (d'.)$$

For the values p_1 and p_2 of p, the third of the above equations (c'.) gives $\cos\gamma=0$; and the equation

$$\cos^2\alpha+\cos^2\beta+\cos^2\gamma=1$$

gives

$$\cos\beta=\sin\alpha;$$

and eliminating p and β from the two first of equations (c'.), we obtain

$$\tan 2\alpha=\frac{2F}{A-B}. \quad \ldots\ldots\ldots \quad (e'.)$$

This corresponds to two values of α differing by 90°. These two values of α, and $\gamma=90°$ (since $\cos\gamma=0$), determine the two positions of the axes of the principal tensions p_1 and p_2. They both lie in the plane of xy.

Taking the third value of $p=p_3=0$, the equations (c'.) are also satisfied by

$$\cos\alpha=0, \quad \cos\beta=0;$$

by which the equation

$$\cos^2\alpha+\cos^2\beta+\cos^2\gamma=1$$

is reduced to

$$\cos\gamma=\pm 1.$$

These values of α, β, and γ correspond to the axis of z, showing that axis along which the pressure $=0$ to be the third axis of principal tension.

21. In determining the magnitude and direction of T_2, the greatest tangential action, we must bear in mind the remarks in art. 19. The quantities denoted in the preceding formulæ by p_1, p_2, p_3 are the same as those denoted in art. 18 by A_1, B_1, C_1. The former are here retained for greater distinctness. If $A+B$ be $>M$, p_3 will be positive, and the order of the principal tensions will be p_1, p_2, p_3. The axis of y will then be the mean axis, and the direction of the maximum tangential action, T_2, will bisect the angle between the other principal axes of x and z. Also we shall have

$$\left.\begin{aligned} T_2&=\tfrac{1}{2}(p_1-p_3)\\ &=\tfrac{1}{2}\{A+B+M\}.\end{aligned}\right\} \quad \ldots\ldots\ldots\ldots \quad (f'.)$$

If, on the contrary, $A+B$ be $<M$, p_3 will be negative, and the order of the principal tensions will be p_1, p_2, p_3. The direction of T_2 will be perpendicular to the axis of z, bisecting the angle between the principal axes of x and y. Also we shall have

$$\left.\begin{aligned} T_2&=\tfrac{1}{2}(p_1-p_3)\\ &=M.\end{aligned}\right\} \quad \ldots\ldots\ldots\ldots \quad (g'.)$$

These two cases hold when

$$M<\text{or}>A+B$$

respectively, or

$$\left.\begin{aligned} &(A-B)^2+4F^2<\text{or}>(A+B)^2,\\ &F^2<\text{or}>AB;\end{aligned}\right\} \quad \ldots\ldots\ldots\ldots \quad (h'.)$$

or the second case may hold when A and B are both tensions, or both pressures, provided one of them be small; and it must necessarily hold when one is a pressure and the other a tension.

22. *Solution of the General Equations to a Second Approximation.*—In proceeding to second approximation I include C and E, but regard their magnitudes as small. These magnitudes must be expressed by the ratios which they bear to some standard force. The greatest value which the tangential force F can attain in any glacier must be limited by the *tangential cohesive power* of glacial ice; for if F exceeded this latter force, dislocation, by a tangential sliding of one element past another, would instantly ensue. Let this tangential cohesion be measured by F_1; then, when it is said that C and E are small,

it is meant that the ratios $\frac{C}{F_1}$ and $\frac{E}{F_1}$ are small ratios. This is equivalent to the assuming that the force on any element parallel to the axis of z is small, and that the couple with reference to an axis parallel to that of y, is also small. The condition $D=0$ signifies, as in the first approximation, the absence of a couple on every element, with reference to an axis parallel to that of x.

Hence putting $D=0$ in our general cubic, we have

$$(A-p)(B-p)(C-p)-E^2(B-p)-F^2(C-p)=0,$$

or

$$\{(A-p)(B-p)-F^2\}(C-p)=E^2(B-p).$$

Putting $C=0$ and $E=0$, we have, as before, for the three first approximate values of p,

$$\left.\begin{aligned} p_1&=\tfrac{1}{2}\{A+B+\sqrt{(A-B)^2+4F^2}\},\\ p_2&=\tfrac{1}{2}\{A+B-\sqrt{(A-B)^2+4F^2}\},\\ p_3&=C. \end{aligned}\right\} \quad \ldots\ldots\ldots \quad (d'').$$

To proceed to a second approximation, put

$$p=p_1+\varpi_1$$

in the cubic, and we obtain

$$\{(\overline{A-p_1}-\varpi_1)(\overline{B-p_1}-\varpi_1)-F^2\}(\overline{C-p_1}-\varpi_1)=(B-p_1-\varpi_1)E^2,$$

or

$$\{(A-p_1)(B-p_1)-F^2-(A-p_1+B-p_1)\varpi_1+\varpi_1^2\}(C-p_1-\varpi_1)=(B-p_1-\varpi_1)E^2.$$

The first approximation gives

$$(A-p_1)(B-p_1)-F^2=0;$$

and the preceding equation shows that ϖ_1 must be of the order E^2. We may therefore neglect terms in $\varpi_1 E^2$, and ϖ_1^3, and we then obtain

$$-(A+B-2p_1)(C-p_1)\varpi_1=(B-p_1)E^2,$$

and

$$\varpi_1=-\frac{p_1-B}{A+B-2p_1}\,\frac{E^2}{p_1-C};$$

or, since C is small,

$$\varpi_1=\frac{p_1-B}{2p_1-(A+B)}\cdot\frac{E^2}{p_1^2}\left(1+\frac{C}{p_1}\right)p_1.$$

ϖ_2 and ϖ_3 may be found in the same manner.

23. Again, equations (*c.*), art. 16, become, if $D=0$,

$$\left.\begin{aligned} (A-p)\cos\alpha+F\cos\beta+E\cos\gamma&=0,\\ F\cos\alpha+(B-p)\cos\beta&=0,\\ E\cos\alpha+(C-p)\cos\gamma&=0, \end{aligned}\right\} \quad \ldots\ldots\ldots \quad (c'').$$

The two last equations give

$$\cos\alpha=-\frac{C-p}{E}\cos\gamma,$$

$$\cos\beta=\frac{F}{B-p}\,\frac{C-p}{E}\cos\gamma.$$

If we were to substitute these expressions in the first equation, we should obtain the cubic in p used in the immediately preceding articles for the approximate determination of its value. Substituting the values of $\cos\alpha$ and $\cos\beta$ in the equation

$$\cos^2\alpha + \cos^2\beta + \cos^2\gamma = 1,$$

we obtain

$$\left\{\left(\frac{p-C}{E}\right)^2 + \left(\frac{F}{p-B}\right)^2\left(\frac{p-C}{E}\right)^2 + 1\right\}\cos^2\gamma = 1,$$

or

$$\left\{(p-C)^2\left(1+\frac{F}{(p-B)^2}\right) + E^2\right\}\cos^2\gamma = E^2.$$

The retention of E^2 in the coefficient of $\cos^2\gamma$ would only produce a term in the expression for $\cos^2\gamma$ of the order E^4, and may therefore be neglected. Also, since p only differs from its first approximate value, p_1, by a small quantity of the order E^2, we may, for the reason just assigned, write p_1 for p in the last equation. Thus we have

$$\cos\gamma = \pm\frac{E}{(p_1-C)\sqrt{1+\left(\frac{F}{p_1-B}\right)^2}},$$

and by substitution,

$$\cos\beta = \frac{F}{p_1-B}\cdot\frac{1}{\sqrt{1+\left(\frac{F}{p_1-B}\right)^2}},$$

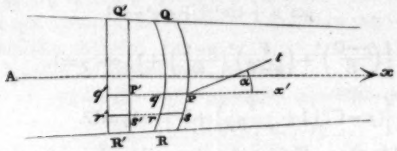
$$\cos\alpha = \frac{1}{\sqrt{1+\left(\frac{F}{p_1-B}\right)^2}}.$$

These equations show that γ is changed from a right angle to one whose difference from a right angle is of the order E, and therefore small; while $\cos\alpha$ and $\cos\beta$ are changed by small quantities of the same order as the difference between p and p_1, *i. e.* of the order E^2.

24. *Nature of the Forces* A, B, C, D, E, *and* F *in the ordinary cases of Glaciers.*—In the preceding investigations we have considered the forces A, B, C, D, E and F as acting on any element of a solid body. In the case of a glacier, this body assumes a specific form, and it becomes necessary to explain what forces are represented by the above symbols in this particular and restricted case. The phenomena with which we shall be here concerned, have been observed almost entirely in those regions of glaciers in which most large ones, like those of the Alps, become much elongated in consequence of the narrowness of the valleys down which they descend. The sides of these valleys frequently approximate to parallelism with each other. The primary general characteristics of the motion of glaciers of this kind are (1) the motion is unaccelerated, (2) the axial portions move with a greater velocity than the marginal portions, and (3) the superficial portions move somewhat faster than the lower portions of the mass. These points are clearly established by observation, independently of any particular theory. In the following articles of this section their truth is assumed.

25. Let fig. 2 represent the section of a glacier by a plane parallel to its surface, and fig. 3 a vertical section through A x the axis of the glacier. Let A x be taken as the

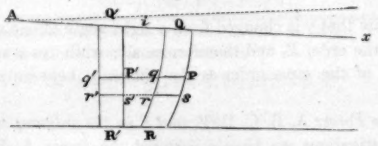
Fig. 2.



Section parallel to the surface.

axis of x, and the surface of the glacier (nearly horizontal) as the plane of xy, a transverse line perpendicular to A x being the axis of y, and a perpendicular to the surface of the glacier the axis of z. Let Q' R' (fig. 2) represent a section, by a plane parallel to that of xy, of an element of the mass lying between two planes perpendicular to the axis of x; Q' R', by the more rapid motion of the axial parts of the mass, will be brought into the position Q R. Also if Q' R' (fig. 3) represent a section of the same element by a vertical plane parallel to that of xz, Q' R' will be brought into the position Q R by the more rapid motion of the upper surface of the mass. Also the small elementary parallelopiped whose section parallel to (xy) is represented by P' q' r' s' in fig. 2, will be brought into the position P q r s, while the section P'$q'r's'$ (fig. 3) of the same element made by a

Fig. 3.



Vertical section.

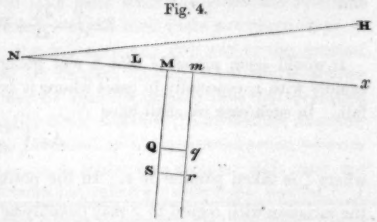
plane parallel to (xz) will be brought to the position P q r s. Thus we see that there will be an *angular distortion* of P q r s about an axis parallel to z, as represented in fig. 2, and a similar distortion about an axis parallel to y, as represented in fig. 3. These angular distortions are respectively due to the couples whose intensities are represented by F and E (art. 15). Also it is easily seen that there will be no twisting or angular distortion of P q r s about an axis parallel to that of x, and that consequently D will $=0$ in all such glaciers as we are now considering. A becomes a *longitudinal* tension, and B a *transversal* one. C will be the pressure on the element parallel to z, and due to the superincumbent weight, and the inclination of the surface of the glacier to the horizon.

26. The intensity of A and B will depend much on the form of the glacial valley. If the sides be parallel, A may be a tension or pressure according to the local variations in

the form of the bed of the valley; B will be small. If the sides be convergent in descending the valley, A will almost necessarily be a pressure, on account of the resistance which the sides will oppose, by their convergency, to the onward progress of the glacier. B will become a great pressure, greater than A, to which it will bear somewhat the same relation as the pressure on the side of a wedge bears to that applied to its back. If the valley be divergent, and if when it becomes so, its inclination is very much diminished (as at the lower end of the Rhone glacier) A may become an enormous pressure, while B may become a tension on account of the lateral expansion which will be given to the mass by the great pressure *à tergo*. C will be best considered in conjunction with E. D, as above stated, will always $=0$. F will have different values for different points in the same vertical transverse section of the glacier. It will manifestly be greatest in the marginal portions, where the angular distortion represented in fig. 2 is greatest; in the central portions, the motion of the glacier will produce very little of this angular distortion about an axis parallel to that of z, and F will be proportionally small.

27. The forces C and E are more dependent on each other than A, B, and F. I proceed to investigate expressions for them. For this purpose let fig. 4 represent a vertical section of the glacier parallel to (xz) and not too remote from its axis; then will F, as above stated, be very small, and may be neglected. Also $D=0$, and B acts perpendicular to the plane (xz), and will therefore not affect the relations between the forces acting parallel to that plane.

Fig. 4.



Let x, y, z be the coordinates of the point Q. We shall have $NM=x$, the distance of the plane N M Q from that of $xz=y$, and $MQ=z$. We might obtain the results required by considering the conditions of equilibrium of the element $\delta x\delta y\delta z$, represented by Q q r S; but it will be more convenient to take an element represented by M Q q m, of which the volume will be $z\delta x\delta y$. I suppose here the existence of a longitudinal pressure parallel to the axis of x, and represented in our general formulæ by A. If we draw a plane through M Q perpendicular to the axis of x, A may represent the intensity of the longitudinal pressure at any point on that plane, referred to a unit of surface. For different points in this plane x will be constant, and the pressure may vary generally with y and z; but it will answer our immediate purpose, and much simplify our problem, if we suppose A constant for every point in M Q, or independent of y and z. It will then vary only in passing from any plane M Q to a consecutive and parallel plane, *i. e.* A will be a function x alone. Hence we shall have

Pressure on one of the sides of the element M q perpendicular to the plane of $yz=A.z\delta y$,

Pressure on the opposite side $=-\left(A+\frac{dA}{dx}\delta x\right)z\delta y$.

The algebraical sum of these pressures, estimated in the positive direction of x,

$$=-\frac{dA}{dx}z\delta x\delta y.$$

Again, if W be the weight of a unit of volume of ice,

$$\text{Weight of the element } Mq=W.z\delta x\delta y,$$

and its resolved part parallel to the axis of x

$$=Wz\delta x\delta y\sin\iota.$$

Also we shall have the tangential force on the base Qq,

$$=-E\delta x\delta y,$$

parallel to the axis of x.

Hence we must have for a condition of equilibrium of the element Mq

$$-\frac{dA}{dx}z+Wz\sin\iota-E=0,$$

and

$$E=\left(-\frac{dA}{dx}+W\sin\iota\right)z.$$

It would seem probable that A will generally vary slowly with y; it may vary more rapidly with z, especially in cases where it becomes large, as at the bottom of an ice-fall. In such case we shall have

$$A=\int_0^z\frac{dA}{d\zeta}d\zeta,$$

where ζ is taken parallel to z. In the position just mentioned (the foot of an ice-fall) the variation with regard to x may possibly be rapid, and therefore $\frac{dA}{dx}$ very considerable. Under the ordinary conditions of a glacier, away from any rapid fall, the variations of A must generally be slow, and the values of $\frac{dA}{dx}$ therefore comparatively small.

C is manifestly due to the resolved part of the pressure of Mq on the surface Qq referred to a unit of surface. The normal pressure on $Qq=W.z\delta x\delta y\cos\iota$. Whence

$$C=Wz\cos\iota.$$

This value of C shows that it must always be small when z is so. Such will also be the case with E, unless $\frac{dA}{dx}$ be very large, which is probably true only at the foot of an ice-fall. Generally, then, we see that C and E will be small for all those depths which lie within the sphere of our observation; and that for all such depths the first approximate solutions of our general equations are sufficiently accurate. The second approximate solutions give the results for greater depths, and indicate the nature of the results for those still greater depths at which C and E might be too large to render the results of the second approximation applicable with sufficient exactness.

We may now distinctly understand the interpretation of the first approximate solutions of our general equations, as applied to the case of an actual glacier. In those

solutions it has been assumed that C, D, and E are so small as to be neglected. D always $=0$, and it follows from the preceding expressions for C and E that, generally, they are relatively small for all those more superficial portions of a glacier to which our observations can extend. Hence, for the same portions, our first solutions will be approximately true and practically applicable.

SECTION IV.—*On the manner in which Dislocations in the Mass of a Glacier, or in its Structure, may be produced; and on the resulting Phenomena.*

28. It will be recollected that the internal pressures and tensions which have been investigated in the preceding pages, are those which would exist in a continuous solid mass acted on by certain external forces, previous to the dislocation which must result from such forces if the intensity of the internal tensions should be sufficient to overcome the cohesion of the mass, or the pressures to overcome its resisting-power. We may, however, carry our geometrical and mechanical analysis of the problem somewhat further, and consider *how* the dislocation will take place when the forces are sufficient to produce it. It has already been remarked (art. 2) that there are three ways in which this may occur. In the first place, the cohesion may give way to the greatest normal tension, p_1; open fissures will then be formed. Again, when the maximum compression (p_3) becomes very great, it may be easily conceived how the primitive structure may break down, as it were, especially if the mass be of a crystalline structure like ice. The third kind of dislocation is that produced by the tangential action between two contiguous elements, which obviously tends to make one element slide past the other, and thus to produce what Principal FORBES has called a "differential motion." I shall consider successively these different kinds of dislocation, and the phenomena which respectively result from them, with reference, in the first place, to the more superficial portions of the glacier, in which our first approximate formulæ are applicable; and secondly, the possible formation of similar phenomena in the deeper parts of the glacial mass.

From the equations (*d'*.), art. 20, we have

$$p_1=\tfrac{1}{2}\{A+B+\sqrt{(A-B)^2+4F^2}\},$$

$$p_3=\tfrac{1}{2}\{A+B-\sqrt{(A-B)^2+4F^2}\},$$

$$\tan 2\alpha=\frac{2F}{A-B}.$$

The last equation gives two values (α_1 and α_2) of α, which determine the directions of p_1 and p_3 with respect to the axis of the glacier. A, B, C, and F, in the application of the formulæ to an actual canal-shaped glacier, are such as described in arts. 25 and 26. We have also the result that the lines of maximum tangential action at any point bisect the right angles between the directions of maximum tension and maximum pressure.

Of the values α_1 and α_2 of α, one will be greater and the other less than 90°; and we must determine, in each problem, which gives the maximum and which the minimum

pressure p_1 and p_2. It may be convenient to consider F an absolute positive quantity; and we may suppose, for such a glacier as that represented in fig. 2, that B=0. In such case the preceding formula shows that one of the values (as α_1) of α must be small and positive when F is small, *i. e.* for any point P (fig. 2) near the axis Ax. Now the maximum tension at P must be due to the tension A parallel to Ax, and that produced by the angular distortion of the element Pqrs. The magnitude and direction of this latter tension are obtained by putting A=0 and B=0 in the above formulæ. This gives the greatest tension =F, the least =−F, and $\tan 2\alpha=\infty$, or therefore $\alpha=45°$ or 135°. From the inspection of the element, it is manifest that the first of these values of α corresponds to the greatest tension produced by the angular distortion. It is from this tension and A that p_1 in the actual case of a glacier before us, must result. Consequently p_1 must act in some such direction as Pt (fig. 2), where α in that figure is acute. The same result will hold if B be of finite magnitude, and algebraically less than A; and thus α_1 and α_2 are distinguished from each other in the case before us, and by similar reasoning may be distinguished in any other case.

29. *Formation of Transverse Crevasses.*—When the maximum normal tension is the force to which the cohesive power of a glacial mass first gives way, the result, as above observed, must be an open fissure, or crevasse, the direction of which must manifestly be perpendicular to that of the tension producing it. These crevasses approximate more or less to right angles with the glacial axis, and usually characterize canal-shaped valleys in which the sides are approximately parallel. In such cases B must be comparatively small; if the valley be slightly convergent, it will be a small pressure, and therefore negative. When these crevasses exist more abundantly, A will doubtless be a large tension, though not necessarily so, as we shall see, for the production of a crevasse.

(1) Taking the simplest case, let us first suppose A=0 and B=0. This may be very approximately true if the glacier descend without acceleration or retardation along a trough-like valley of uniform width and uniform inclination. We shall then have by the above equations, $p_1=$F, $p_2=-$F, and $\tan 2\alpha=\infty$. Hence the direction of maximum tension will make an angle $\alpha=45°$ with the axis of the glacier (Ax) (fig. 2) towards which it will converge in descending. If, therefore, a fissure be formed at all, which can only be in the marginal regions where F is considerable, it must be in a direction perpendicular to Pt, and making an angle of 45° with the axis of the glacier. We have also for the maximum tangential action (art. 21),

$$T_2=\tfrac{1}{2}(p_1-p_2)=F,$$

equal, in this case, to p_1, and making an angle of 45° with the directions of p_1 and p_2. It will therefore be parallel to the axes of x and y. Hence the maximum normal and tangential forces make equal efforts, in this case, to dislocate the mass. Let the tangential cohesive power of the mass be F_1; the greatest value which p_1 can assume will then be also F_1; and if the normal cohesive power (P_1) be less than F_1, the tension p_1 may assume a value (F) between P_1 and F_1, by which a crevasse will be formed in the position above mentioned. Transverse crevasses may therefore be formed without any of

that direct longitudinal tension which might, at first sight, appear necessary to produce them.

(2) If there be a considerable longitudinal tension, but no appreciable transverse pressure, we have

$$p_1=\tfrac{1}{2}\{A+\sqrt{A^2+4F^2}\},$$
$$p_2=\tfrac{1}{2}\{A-\sqrt{A^2+4F^2}\},$$
$$\tan 2\alpha=\frac{F}{A}.$$

Hence p_1, the maximum tension, will be increased, and therefore, also, the tendency to form a crevasse. Likewise the greatest value of α will be less than 45°, and the direction of the crevasse, as we might expect, will be more nearly perpendicular to the axis of the glacier.

(3) Many glacial valleys become narrower as we descend them, and consequently the mass of the glacier may enter each part of the valley as a wedge, and may frequently become more or less compressed. In such case B will be negative, and may become very large. We shall then have

$$p_1=\tfrac{1}{2}\{A-B+\sqrt{(A+B)^2+4F^2}\},$$
$$p_2=\tfrac{1}{2}\{A-B-\sqrt{(A+B)^2+4F^2}\},$$
$$\tan 2\alpha=\frac{F}{A+B}.$$

In this instance, as well as in the preceding one, p_1 will necessarily be a tension, and greatest (A and B being constant) where F is greatest, *i. e.* in the marginal portions of the glacier. For the like reason, α will also be greatest in those portions. It will vanish at the axis, where F vanishes. Hence, if the forces be sufficient to overcome the cohesion of the mass, a curvilinear crevasse may be formed extending across the glacier and meeting its axis at a right angle. This, however, is rarely the case, the transverse crevasses being formed, in general, in the lateral portions only of canal-shaped glaciers, where they will approximate more or less to straight lines. They are most likely to be formed where A is a considerable tension, which is less likely to be the case in converging valleys.

It is important to observe that in all cases in which the expression for tan 2α is positive, *i. e.* where B is algebraically less than A, α must lie between 0 and 45°, and consequently *the inclination of a curved crevasse to a transverse line perpendicular to the axis must likewise always lie between the same limits.* This rule is applicable, according to this theory, wherever transverse crevasses are likely to be formed*.

* An open curvilinear fissure in its *progressive* formation would be in some degree influenced by other causes than the maximum tension at each point through which it might pass. Moreover, the cohesive power has been above supposed to be the same in every direction from any proposed point. There *may*, on the contrary, be planes of *less cohesion*, in which case if the cohesion along any such plane bear a smaller ratio to the internal tension perpendicular to it, than the cohesion perpendicular to the maximum tension bears to p_1, the crevasse may be formed along the plane of least cohesion. I know no reason, however, to suppose that these causes are sufficient to modify in any essential degree the law enunciated in the text.

30. *Formation of Longitudinal Crevasses.*—Transverse crevasses, as above stated, are almost invariably formed in valleys the sides of which are approximately parallel; longitudinal crevasses are as generally formed in valleys in which the sides are divergent, and usually perhaps when they become rather suddenly so. They are found almost exclusively at the lower ends of glaciers. The Rhone glacier affords the best-known example of crevasses of this kind, but M. Agassiz refers to a number of other cases, the greater part of which, however, appertain to small glaciers*. At the foot of the great ice-fall of the Rhone glacier, the valley expands largely, as is well known, and its inclination to the horizon becomes comparatively small. Thus the ice, accumulating at the bottom of the fall, exerts an enormous pressure *à tergo* on the ice immediately before it, and this pressure is propagated onwards in directions which radiate from the bottom of the fall. It is manifest that the force along each radiating line will be a great pressure. Again, if we conceive the whole mass divided into concentric rings perpendicular at each point to the above-mentioned radiating lines, the pressure along these lines will extend the ring, and produce in it a great tension at every point, perpendicular to the direction of the radial pressure above mentioned. Hence if we take any one of these radiating lines as the axis of x, the radial pressure at any point upon it will be denoted by $-A$, and the tension upon it in the direction perpendicular to the axis of x, will be B. The former will be a *principal pressure*, and the latter a *principal tension*; and if crevasses be formed at all, they must be in directions perpendicular to that of B; *i. e.* they must be radial, as they are always observed to be. The glacier of the Rhone is only a type, as regards longitudinal crevasses, of all other glaciers in which they exist.

31. An explanation of the phenomena of transverse crevasses, essentially the same as that above given, though founded on a more restricted mechanical and mathematical analysis of the general problem, was given by me some seventeen years ago. I am not aware that any doubt was entertained as to its validity, but I am also not aware of any glacialist having recognized it previously to Dr. Tyndall. M. Agassiz has given an explanation† both of the transverse and longitudinal crevasses, involving apparently the notion of the oblique tension which, I have proved, must necessarily exist in a determinate direction. The mechanical reasoning employed, however, is too vague to constitute a mechanical explanation of the phenomena. Moreover his work was published in 1847, three or four years after my memoir containing the preceding explanation was printed in the Transactions of the Cambridge Philosophical Society. Principal Forbes, also, speaks of a *drag* from the sides towards the centre of a glacier‡, but with the view apparently, not of explaining the formation of transverse crevasses, but of the veins in cases of the veined structure. His "lines of greatest strain" must therefore, I conceive, mean the same lines mechanically, not as my lines of greatest *normal* tension, to which the crevasses are unquestionably due, but my lines of greatest *tangential* action. If he supposed these two directions to be identical, it was a manifest error; for

* Système Glaciaire, p. 324. † Ibid. p. 320 *et seq.*

‡ Occasional Papers, p. 57; also last chapter of his 'Travels.'

I have proved that they must in all cases differ by an angle of 45°. I have thought it right to say thus much to vindicate my claim to having been the first to give any explanation, founded on true mechanical principles, of the phenomena in question.

32. That the theoretical law above enunciated with respect to the directions of transverse crevasses is the actual law, is determined, I conceive, beyond all doubt. It was, in fact, so distinctly recognized by M. Agassiz and others*, before careful observations had been made on glacial motion, that it was regarded as a proof that the sides of a glacier moved faster than its central portion. But the best and, I believe, the only accurate recorded evidence on the subject is that afforded by the admirable map published by M. Agassiz, of the glacier of the Aar. There the crevasses, in a particular locality, are laid down with geometrical accuracy, and the eye recognizes at once the law in question, notwithstanding the minor deviations which must necessarily result in such a case from local and irregular causes†. Principal Forbes, however, does not seem to recognize this law; for he observes‡ that he agrees with some preceding observers in believing crevasses to be mere *accidents* of glacial motion. I have, however, demonstrated, as I had done before the publication of the paper in which this opinion is expressed, that though a glacier should be affected by no irregularities of surface along its margins or bed tending to dislocate it, the internal tensions arising from the more rapid motion of its central portions would always tend to produce oblique transverse marginal fissures. Local and irregular causes may frequently counterbalance this tendency; but the cause itself which produces these fissures is no more *accidental* than the law of the motion in which it originates. It might as well be asserted that the longitudinal or radiating crevasses of the lower part of the glacier of the Rhone were merely accidental phenomena,—an assertion which few glacialists, I imagine, would venture to maintain.

33. The positions of the crevasses as above determined, will be those in which they are originally formed. It is manifest that transverse crevasses will change their angular positions with reference to the axis of the glacier, by the more rapid motion of its axial portion. They will thus become more approximately perpendicular to the axis. Moreover, as they deviate from their original positions, less force will be exerted to keep them open, and to counteract any independent or local causes tending to close them. They do thus finally disappear, and generally at points not remote from those where they were originally formed, and where local conditions probably aided their formation. A closing up of the crevasses after a certain time, presents no difficulty; but the entire

* Système Glaciaire, p. 305.

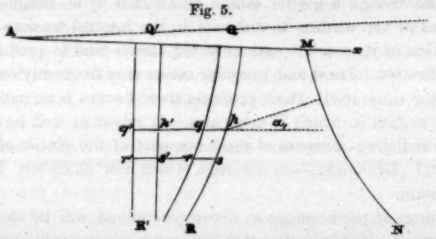
† I cannot here omit the expression of my conviction of the inadequate justice which has been rendered in this country to the 'Système Glaciaire' of M. Agassiz. It professes to be, as it is, principally descriptive, and contains more accurate details on many points than any other work professes to offer. The map which accompanies it, founded on the very careful trigonometrical survey of M. Wild, is full of beautifully delineated details. We possess no other glacial document of the kind at all comparable to it. I shall have other occasions to refer to it.

‡ Occasional Papers, p. 151.

disappearance of all traces of them, and the resumption of complete crystalline continuity in those parts of the mass in which these crevasses had previously existed, remained a difficulty of which no physical explanation had been given till the experiments of Dr. TYNDALL afforded so happy a solution of it by proving that the renewed continuity was attributable to regelation resulting from the renewed contact of portions of the ice which had been previously separated.

34. *Formation of Crevasses in the deeper portions of a Glacier.*—The formation of crevasses in this position must ever perhaps remain a matter of speculation; for we can have little hope of making their existence a matter of observation. The general direction of maximum tension at any point of a glacier at a great depth, cannot be exactly determined, because the general equations (*c.*), art. 16, cannot, for this case, be generally solved. It will be easy, however, to determine this direction in terms of the internal forces for any point in the vertical plane through the axis of the glacier, and, consequently, the section made by that plane with the surface to which the direction of the maximum force is a normal—the surface along which the crevasse would be formed. For this purpose let fig. 5 represent the vertical section through the axis of the glacier.

Fig. 5.



The undistorted element Q′ R′ will be brought by the more rapid motion of the surface into the position Q R, as described in fig. 3. The internal forces acting on the small element $p\,q\,r\,s$ will be A, B, C, and E, the latter producing the couple whose axis is parallel to that of y. It is manifest, however, from the conditions of symmetry, that the direction of the maximum tension must lie in the vertical plane through the axis of the glacier, and will not be affected by B, which, as in other cases of transverse fissures, must be supposed either a pressure or a comparatively small tension. Hence, putting $-$C for B and E for F in our formulæ (*c'.*), art. 20, we have

$$\tan 2\alpha = \frac{2E}{A+C}.$$

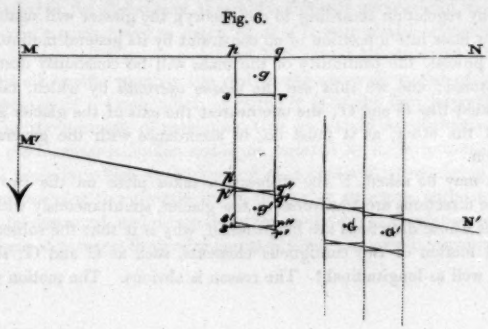
The angle α is indicated in fig. 5 (see art. 28 and fig. 2). Near the surface, E and therefore α, vanish, and the crevasse, if formed, will be vertical. At lower points of the mass α will increase with E, and the vertical section of the crevasse will resemble the curve M N in the figure.

The maximum tension in the marginal portions of the glacier will be increased by F; and it is in those portions, near the lower as well as near the upper surface of the mass, that crevasses will be most likely to be formed. The forces tending to form them may probably be much the same in both cases; but the tendency of the incipient fissures to open into wide crevasses must almost necessarily be much counteracted near the lower surface by the action of the bottom of the valley on that surface. The sides of a fissure will not there be able to separate from each other with the same facility as at the free surface of the mass. In fact any incipient fissure formed within the glacier and not extending to its external surface, will have much less of this facility of subsequently opening, than those which are formed nearer to the outer surface and directly communicate with it. I therefore conceive it to be very improbable that crevasses exist in the deeper portions of a glacier, equal in number and magnitude to those which are seen in its more superficial portions.

35. *Effects of the Crushing of the Mass.*—It may frequently happen that the maximum pressure (p_2) at any proposed point of a glacial mass shall be much greater than the maximum tension p_1, or the maximum tangential force T_2 (art. 18) at that point; and the dislocation may be produced by the crushing power of p_2. The element may thus be broken into a greater or smaller number of fragments, and the constraint of the mass removed. Its onward motion will then be continued, and its continuity restored by regelation, till a repetition of the process becomes necessary to overcome a new state of constraint. It is in this manner that the property of regelation enables us so beautifully to account for the molecular mobility of a glacial mass, and the consequent freedom of its central to move more rapidly than its marginal portions, without any reference whatever to the property of viscosity or plasticity.

36. *Dislocation produced by the Tangential Force.*—The third way in which the mass may be dislocated is, that the tangential cohesion may yield to the tangential force on any proposed element, as explained in article 28. For the greater simplicity of explanation, I shall suppose the sides of the valley parallel, and $A=0$, and $B=0$. Also we take $C=0$ and $E=0$ as in our first approximate solutions. Let $p\,q\,r\,s$ (fig. 6) be the

Fig. 6.



section of a small elementary rectangular parallelopiped (δx, δy, δz) made by the plane of the paper (that of xy); and let $p\,s$ be in the direction ($p\,p'$) of the motion of p; it will be parallel to x, and the transverse line M $p\,q$ N, perpendicular to $p\,p'$, will be parallel to y. Now the physical line M N will, in a short time, come into the position M′ N′, by the assumed motion of the glacier, and the greater velocity of its axial portion. The element $p\,q\,r\,s$ will then come into the position $p'q'r's'$, and will be angularly distorted. It will be acted on by the tangential force (F), forming two equal and opposite couples, with a common axis parallel to z (art. 29, (1)), and tending to destroy the continuity on every side of the element, by overcoming the tangential cohesion. The force F will be different for different angular positions of the element, and will always be greatest when the sides of the element bisect the two right angles between p_1 and p_2, the greatest tension and the greatest pressure (art. 18). In the present case the directions of p_1 and p_2 will each be inclined at an angle of 45° to the axes of x and y (art. 29, (1)); and therefore the intensity of the forces (F) of the two couples will be greatest when they act respectively parallel to x and y, i. e. when the element is in the angular position represented in the figure.

Now if tangential dislocation take place, it must necessarily do so in those directions in which the tendency of the forces F to produce it is greatest, or, in the case before us, in directions parallel and perpendicular to the axis of the glacier, the tendencies being the same in both those directions. Let us suppose, then, a complete tangential rupture to take place, and simultaneously, on each side of the element $p\,q\,r\,s$, as well as in the surrounding elements. Each element, represented by $p'q'r's'$, will then regain its original rectangular form by its *elasticity*, but so moving that its centre of gravity (g') shall remain at rest, since the elastic force of restitution acts entirely within the element. Thus $p\,q\,r\,s$ will return to its original rectangular form $p''q''r''s''$; and if we take two consecutive elements whose centres of gravity are G and G′, they will be brought into the relative positions represented in the figure, in which G′ is slightly in advance of G, as much, in fact, as is necessitated by the more rapid motion of the central parts of the glacier. After the rupture, if we suppose the continuity to be instantaneously restored (as it will be by regelation according to our theory), the glacier will again be brought as a continuous mass into a position of no constraint by its general motion. By a repetition of this process, the continuity of the mass will be constantly destroyed and as constantly restored; and we thus see the *modus operandi* by which, taking any two elements situated like G and G′, the one nearest the axis of the glacier gets gradually in advance of the other, as it must do, in accordance with the general law of the glacier's motion.

37. But, it may be asked, if the dislocation takes place on the two sides of the element whose directions are transverse to the glacier, simultaneously with the rupture along the sides whose directions are longitudinal, why is it that the subsequent relative or differential motion of two contiguous elements, such as G and G′, should not be transversal as well as longitudinal? The reason is obvious. The motion which instan-

taneously takes place after the tangential dislocation is a motion of rotation *about* G, the centre of gravity of the element, by which that point is not affected; whereas the motion with which we are here concerned, as that which alone can possibly produce any finite differential motion, is the motion of the centre of gravity (G) *itself*, arising from the general onward progress of the whole mass. Any real differential motion between two particles must, in all cases (whatever, in fact, may be the directions of tangential dislocation), take place in the actual direction of the motion of the particles. Thus, if the directions of tangential dislocation be not parallel and perpendicular to the axis of the glacier, as in the above case, the true differential motion of two particles must still take place in the actual direction of their motion.

38. In the above case we have assumed the rupture to be complete and simultaneous on every side of the element, and also the absence of friction between contiguous elements. If it be otherwise, as it doubtless will be, the same reasoning will be applicable; but the relief of the constraint of the mass, or of any element, at each dislocation will be only partial, and the consequent differential motion will be somewhat less. In such case the facility with which the central portions of the mass move faster than the other parts will be diminished.

39. I am not here supposing that this tangential dislocation is the most probable mode by which the constraint of the glacial mass is commonly relieved under great pressure. The crushing of its elementary portions (art. 35) would appear, perhaps, a more likely *modus operandi*; but possibly both these processes may contribute to the actual dislocations (without finite fissures) by which the constraint of the mass is instantaneously relieved. If the dislocations were entirely tangential, it is easily seen that two contiguous elements, like G and G′ (fig. 6), would ultimately be separated, while each should preserve its physical identity. Consequently, identical particles forming at one time the continuous transverse linear element, M N, might subsequently be converted into an elongated loop which should be discontinuous in the marginal parts of the glacier, where the differential motion would be greatest, and continuous in the central portions, where that motion would be least. If, on the contrary, each element should be *crushed* in the dislocation, it would manifestly never regain its primitive form, but would become compressed or extended *as if* it were plastic or viscous (art. 4, &c.). In such case the original transverse element M N would be converted into a continuous loop. But, at all events, whether the real *modus operandi* consist of only one of the above processes, or of a combination of both, it is of the first importance for a just appreciation of the principle of regelation, that we should see distinctly how the continuity of the glacial mass is broken and again restored by it, in contradistinction to the effect of real viscosity, which would prevent that continuity from being broken at all. In the latter case also there would be no particular structure, such as the crystalline structure, to be destroyed, and no necessity for the power of regelation to restore it. It is in the difference between the *modus operandi* when the mass is viscous, and that when

the mass is crystalline and brittle, that we see best, perhaps, the distinction between the Viscous and Regelation Theories.

Section V.—*On the Veined Structure of Glacial Ice.*

40. Two different theories, as is well known, have been proposed to account for the curious structure frequently observed in glacial ice, and termed the laminar, veined, or ribbon structure. The preceding investigations bear intimately on these theories. One of them, that of Principal Forbes, asserts the structure to be due to the sliding of one thin lamina of ice past another, or to their differential motion—a process by which he supposes extensive portions of the mass to be divided into slices, usually nearly vertical, and not exceeding, in many cases, the fraction of an inch in thickness. His first idea was that these parallel discontinuities were, after their formation, filled with infiltrated water, which, by being frozen, formed the veins of blue ice. He afterwards appears to have abandoned this notion; but what physical process he supposed to be substituted for infiltration I have not been able distinctly to ascertain. This, however, is not material as regards the examination which I propose to give this theory in the sequel. The other theory above alluded to is that first proposed by Dr. Tyndall, an essential point in which is that the laminæ of ice which characterize this structure must be perpendicular at each point to the direction of greatest pressure there. So far alone my researches are related to this theory, and so far only shall we be here concerned with it. I shall not discuss the manner in which this pressure is supposed to produce the lamination in question, a point on which somewhat different opinions have been propounded. It is the mechanical part only of the theory that I shall discuss. It has been called the *pressure theory* of the veined structure, while that advocated by Principal Forbes has been termed the *differential theory* of the structure. The lines in which the laminæ of blue or white ice meet the surface of the glacier will generally be curved lines, which I shall designate as *lines* or *curves of structure*.

This structure, as well as the lines depending upon it, have received different designations according to the portion of the glacier where it is found, or the directions of the lines of structure. Thus, when found in the lateral portions of the glacier, Dr. Tyndall has termed it the *marginal structure*. It is frequently found in canal-shaped glaciers. The lines of structure in such cases are usually inclined at small angles to the sides of the glacial valley. When the lines stretch more directly and entirely across the valley, the structure is said to be *transverse*, and is more especially developed at points below an ice-fall and not remote from it. In the axial part of a glacier the lines of structure are frequently longitudinal, or parallel to the axis. The structure is then called *longitudinal*. It is generally best exhibited at the confluence of two large glaciers, as those of the Finsteraar and Lauteraar. It may be convenient to preserve these designations, though, as will be seen, they are the results, according to the pressure theory, of the same general cause, modified by the local conditions under which it acts. I take again

the first approximate solutions of our equations, as applicable to all usually accessible depths.

41. *Pressure Theory of the Laminated Structure.*—We have generally,

$$p_1=\tfrac{1}{2}\{A+B+\sqrt{(A-B)^2+4F^2}\},$$

$$p_2=\tfrac{1}{2}\{A+B-\sqrt{(A-B)^2+4F^2}\},$$

$$\tan 2\alpha=\frac{2F}{A-B}.$$

In the formation of crevasses, we have been principally concerned with p_1 and its direction, we shall now be more especially concerned with p_2, when a pressure, and the corresponding value of α; but it will be convenient to bear in mind that, according to the fundamental principle of this theory, the curve of structure through any point will always coincide with the direction of p_1, the maximum tension or minimum pressure at that point, p_2 being always the maximum pressure there. Also, since the direction of p_2 is horizontal (neglecting C and E as in our first approximation), each laminar surface must be vertical, and will therefore be completely determined by the line of structure corresponding to it.

42. *Formation of the Marginal Structure.*—I have stated that this is frequently found in canal-shaped glaciers. Suppose the glacial valley to be more or less convergent, so that the transverse force B may become a pressure; and suppose its magnitude to be greater than that of A, as it probably will be generally in such a valley. We may also suppose A to be a pressure, though this is not essential for the production of the laminar structure in the case before us. The preceding formulæ now become

$$p_1=\tfrac{1}{2}\{-A-B+\sqrt{(B-A)^2+4F^2}\},$$

$$p_2=\tfrac{1}{2}\{-A-B-\sqrt{(B-A)^2+4F^2}\},$$

$$\tan 2\alpha=\frac{2F}{B-A}.$$

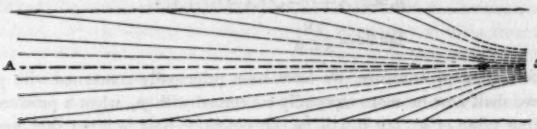
p_2 will be the maximum pressure, and the structural curve at any proposed point will be perpendicular to the direction of p_2; it will therefore coincide with that of p_1, which will be determined by the above expression for $\tan 2\alpha$. Let α_1 be the value of α which gives the direction of p_1, or that of the curve of structure at any proposed point. Then will α_1 lie between 0 and 45°. At points near the axis of the glacier, the *twisting* tendency, and therefore F also, will be very small, and may be neglected. We shall then have

$$p_2=-B.$$

Let us first suppose B too small to produce the veined structure. It will not, in such case, exist at all in the central portion of the glacier. At any point more remote from the axis, p_2 will be increased by the increase of F, and may become sufficient to produce the structure. α_1 will be greatest when F is so, *i. e.* at the sides of the glacier, supposing A and B to remain constant. Should B be much larger than F, as we should antici-

pate in the cases we are considering, α_1 will be much less than 45°, the greatest value to which it can attain when the transverse pressure B predominates over the longitudinal pressure A. The lines of marginal structure will be as represented in fig. 7, by the continuous portions of the oblique lines.

Fig. 7.



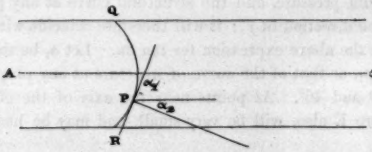
43. *Formation of the Longitudinal Structure.*—If B, the transverse pressure, be very great, p_2 may be sufficient to develope the veined structure in the central as well as the marginal parts of the glacier. The curves of structure will then be continued towards the axis of the glacier, to which they will constantly converge as an asymptote, as represented by the discontinuous lines in fig. 7. If B be very large, the lines of structure, when examined only in a limited area, will be sensibly parallel to each other and to the sides of the glacier.

44. *Formation of the Transverse Structure.*—Let us now suppose the longitudinal pressure A to be very great, as it must be, for instance, at the bottom of an ice-fall. We may also suppose it much greater than B. We shall then have

$$\tan 2\alpha = -\frac{2F}{A-B},$$

and consequently 2α will either be a small negative angle, or positive and nearly equal to 180°; and therefore α will either be small and negative, or positive and nearly equal 90°. The former must, from the nature of the case, correspond to the direction of maximum pressure, and must therefore be α_2, and the other α_1, as in fig. 8. α_2 will $=0°$ at

Fig. 8.



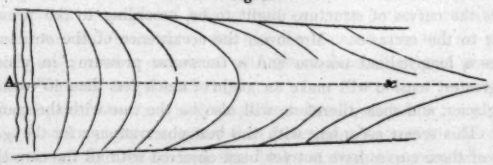
the axis, and will be greatest at Q and R. If A be sufficiently great, the curve of structure will be continued across the glacier, constituting the transverse structure.

45. There are two cases connected with the formation of the transverse structure at the bottom of an ice-fall which ought to be noticed. It may happen that the valley below the fall shall be an elongated slowly *converging* valley, or, as occurs perhaps more rarely, a rapidly diverging one like that already described at the extremity of the Rhone

glacier. In the first case, especially if the inclination of the valley should gradually increase and become considerable, the transverse pressure, B, may be much increased, and the longitudinal pressure, A, much diminished as we descend the valley, till it becomes less than B. In such case the curves of structure (so far as they depend alone on the action of the external forces) would become more and more elongated, as represented approximately in fig. 9. If B should become greater than A,

$$\tan 2\alpha = \frac{2F}{B-A},$$

Fig. 9.



and the case becomes the same as that previously considered (art. 43), in which the formation of the longitudinal structure is explained. So long, however, as A remains a pressure sufficient to produce the laminar structure at right angles to the axis, the loops will be completed; if A become too small to produce the structure, the curves will not be continued across the axis, and the structure will exist only as a marginal structure; and if B still increase (by the glacial valley becoming very narrow), so as to produce the longitudinal structure along the axis, the structure will become longitudinal, as represented by the two lower lines of structure in fig. 9.

46. In the second case above mentioned, of a rapidly divergent valley of small inclination, the mass will be urged onwards by a great radial force, as above explained (art. 30), and the curves of structure will be perpendicular to the crevasses, and consequently approximately concentric about the foot of the ice-fall, where this structure commences.

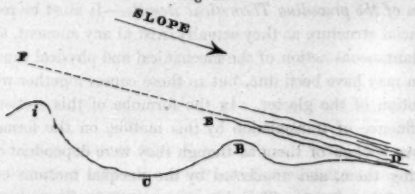
47. *Application of the preceding Theoretical Results.*—It must be recollected that the phenomena of glacial structure as they actually exist at any moment, are not merely the results of the instantaneous action of the mechanical and physical causes to which their original formation may have been due, but to those causes together with the effect produced by the motion of the glacier. In the formulæ of this section I have entirely neglected the influence of transmission by this motion, on the forms of the curves of structure, and have spoken of them as though they were dependent only on the forces originally producing them, and unaffected by the unequal motions of the central and marginal portions of the glacier. This, however, cannot be the case, unless we suppose the structure to be modified at every instant in exclusive obedience to the physical and mechanical causes in which it originates—a supposition having a great apparent improbability. The motion of a glacier being known, it is merely a geometrical problem to

point out accurately the nature of the modification which would be produced in a given curve or surface of structure by transmission alone; the amount of that modification can only be known by observation. I shall investigate this subject in a subsequent section. At present, in the application of the preceding formulæ to particular cases, my conclusions will be restricted to the hypothesis of the structure being due alone to the instantaneous action of the forces tending to produce it in each particular locality.

48. The *marginal structure* is found more or less developed in most canal-shaped glaciers. It has been best observed, perhaps, on the glacier of the Aar and its tributaries, and on the glaciers at Chamouni. It sometimes coexists with marginal crevasses. In such cases the curves of structure ought to be, according to the pressure theory, perpendicular to the crevasses. Moreover, the coexistence of the structure and crevasses implies a longitudinal tension and a transverse pressure; in which case the direction of greatest tension will make an angle of much less than 45° with the axis or sides of the glacier, and such, therefore, will also be the case with the marginal curves of structure. This seems accordant with the best observations; for though the forms and positions of these curves have not yet been observed with all the care they require, there is little doubt as to their meeting the sides of the glacier at finite angles. The law of perpendicularity between the structural curves and the crevasses was first observed, I believe, by Principal Forbes on the glacier of the Aar; and in speaking of the Talèfre glacier* he remarks, "The crevasses as they present themselves are convex towards the origin of the glacier, and here, as in other cases, perpendicular to the veined structure." The same impression appears to have been produced on other observers.

49. It is manifest that the marginal structure may be modified by any local conditions which affect the internal pressure of the glacier. Principal Forbes describes what he regards as an extraordinary case, and one to which he appeals as affording a crucial test in favour of his own views†. It is furnished by the glacier of La Brenva, and is represented by fig. 10. The line i C B D represents the side of the glacial valley,

Fig. 10.



in which projections at B and D appear to form a somewhat sudden obstacle to the onward motion of the glacier in the direction F D. Now it is certain that the maxi-

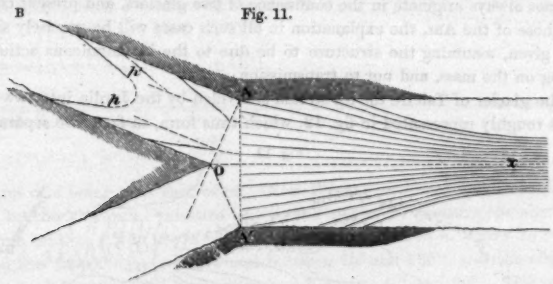
* Occasional Papers, p. 192. † Ibid. p. 56.

mum pressure between B and D would be very great, and that its direction would be nearly perpendicular to that of the motion of the glacier. Consequently the direction of the veins, according to the pressure theory, ought to coincide approximately with the direction of the motion, as represented by the lines between B and D. The example, as I understand it, presents no difficulty in the pressure theory*.

50. The *transverse structure* is well developed near the bottoms of the ice-falls of the upper part of the Glacier du Géant, and that by which the ice is precipitated from the glacier of Talèfre to that of Léchaud; but the most striking exhibition of it is afforded by the lower end of the Rhone glacier, which has already been mentioned (art. 30) as affording an excellent example of longitudinal, or, more properly, radiating crevasses. The curves of structure, according to the law above stated (art. 48), are perpendicular to the crevasses, and therefore coincident with the surfaces of greatest pressure, as they ought to be according to the pressure theory.

51. The *longitudinal structure* is perhaps best developed below the junction of the Finsteraar and Lauteraar glaciers, where they form the glacier of the Aar†. The marginal structure is well exhibited along the flanks of both the tributaries, and is continued along those of the combined glacier resulting from their union. It is from the point of junction O, fig. 11, and on each side of the axis Ox, that the longitudinal

Fig. 11.



structure is so finely developed. The tributary B A represents the Lauteraar glacier. The oblique lines on either flank represent the marginal structure, which is supposed to extend only to a certain distance from the sides. The whole width of the glacier of the Lower Aar is much less than the sum of the widths of its two principal tributaries, so that the transverse pressure (especially near the axis), for some distance below the

* I may remark that I see nothing distinctive in the observations made by Principal Forbes on La Brenva to determine the relative velocities of points at different distances from the side of the valley. Exactly similar results would be obtained on any glacier in which the velocity of the central should be considerably greater than that of the marginal portions.

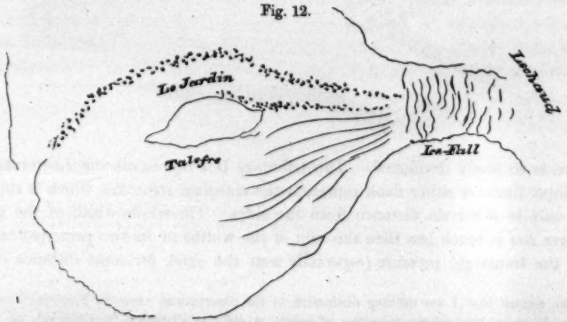
† Tyndall's 'Glaciers of the Alps,' p. 387.

junction, must manifestly be enormous. About some such section as O A this pressure will begin to be felt, and will be in full operation about A A′. Now considering the direct effects which would be produced by the forces acting on the united glacier below the section A A′ (independently of the effects of transmission), that portion will present precisely the case of longitudinal structure considered in art. 43. The transverse pressure, as above remarked, will be enormous, especially along the axis, to which it will there be perpendicular, and the general structure will be such as is represented in fig. 7, and repeated in fig. 11. The maximum pressure at any point in the axial part of the glacier will be increased by the mutual action of the two tributaries after their confluence, required to divert each from its original direction; and in the marginal parts of the great glacier the maximum pressure will be increased by the comparatively large value of F. In the region intermediate to the marginal and central portions, the pressure will probably be less than in either of those portions, but in the figure it is supposed to be sufficient to superinduce a longitudinal structure. In this case, however, the angle α at any point P would not increase regularly, and the curves in the part of the glacier now referred to might present some degree of inflexion.

According to Dr. TYNDALL, the longitudinal character of the veined structure is strongly developed, as a general rule, under all considerable central moraines; and as such moraines always originate in the confluence of two glaciers, and present conditions similar to those of the Aar, the explanation in all such cases will be precisely similar to that above given, assuming the structure to be due to the instantaneous action of the forces acting on the mass, and not to transmission.

52. In the glacier of Talèfre the ice-stream is divided by the Jardin into two separate currents, as roughly represented in fig. 12, which thus form, in fact, two separate tribu-

Fig. 12.

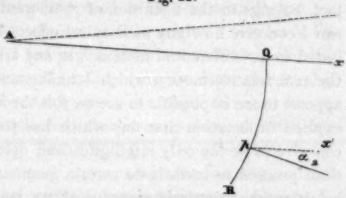


taries to the united glacier which proceeds, below the Jardin, to precipitate itself over the ice-fall of Talèfre. Principal FORBES appears to have examined the veined structure carefully, and describes it as represented in the figure by the fine lines converging to the

fall. The dotted lines are moraines, and indicate the course of the ice-current. It is manifest that the mass, in approaching the fall, must suffer immense transverse compression, which accounts for the longitudinal structure in that part of the glacier.

53. *Formation of the Veined Structure in the deeper portions of a Glacier.*—We cannot determine completely the direction of the greatest pressure at any proposed point at a great depth in a glacier, for the reason above assigned (art. 34). That direction would give us the normal to the surface of greatest pressure, and therefore, also, to the surface of structure through that point, whence the differential equation to the surface would be known. In our practical inability to follow this method, we may proceed, as in art. 34, to determine the section of the required surface made by a vertical plane through the axis of the glacier. In a glacier of considerable width, the sections of this surface made by planes parallel to the one just mentioned, will be very similar to the axial section; because the velocities will be very nearly the same for all points in a transverse line on the surface of the glacier, within considerable distances of the axis*; and the same therefore must also hold for points at greater depths. The most important case is that which occurs at the base of an ice-fall in which A becomes very large and a pressure. Also B, the transverse force, may be considered much smaller than A, and a pressure. Our general formulæ will become

Fig. 13.



$$p_1 = -\tfrac{1}{2}\{A+C-\sqrt{(A-C)^2+4E^2}\},$$

$$p_2 = -\tfrac{1}{2}\{A+C+\sqrt{(A-C)^2+4E^2}\},$$

$$p_3 = -B;$$

and we shall have, also,

$$\cos\beta = 0, \quad \tan 2\alpha = -\frac{2E}{A-C},$$

the plane of α being now that of xz. Now B being supposed small compared with A, p_2 will be the maximum pressure and p_1 the minimum pressure, or algebraically the maximum tension. The above equation gives two values of α. Now 2α must be negative and less than 90°, or positive and between 90° and 180°; and therefore α must be negative and less than 45°, or positive and between 45° and 90°. The negative value will evidently here correspond to p_2 the greatest pressure. A may possibly be much the same at different depths, in our present case, and E (art. 34) will be zero at the surface, and will increase with the depth. C also increases with the depth, as does, therefore, *cæteris paribus*, the negative angle α_2. It must always, however, be less than 45°, so long as C is less than A, whatever may be the depth; and near the surface it will vanish.

* M. Agassiz has best exemplified this in his admirable map and diagrams of the glacier of the Aar already referred to. He there delineates (Atlas, pl. 4) the forms assumed by an originally straight transverse physical line on the glacier near the junction of its two great tributaries in three successive years. The motion of different points on the central portion of the mass do not differ much throughout a breadth of nearly one-half of the glacier.

The axial section of the surface of structure may be represented by Q R in fig. 13, varying in its inclination to the nearly vertical axis of z from zero to less than 45°. A similar conclusion will hold, as above stated, for all the central portion of the glacier.

The structure here considered is manifestly a transverse structure, and is probably only formed where there is a sudden change of inclination in the bed of the glacier, like that at the foot of an ice-fall. The intensity of the longitudinal pressure to which it is there due, may possibly diminish rapidly in receding from the fall; and so far it would follow that, where the structure is continued to any considerable distance from the locality in which it was formed, it must be due in a great degree to transmission. But this is a question which I reserve for further discussion.

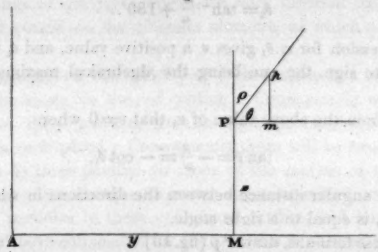
54. *Differential Theory of the Veined Structure.*—The idea on which this theory is founded has already been stated at the beginning of this section (art. 40); and the modes in which dislocation may take place so as to admit of the more rapid motion of the central portion of a glacier, have been explained. It has also been pointed out (art. 36) that the real differential or relative motion of two contiguous particles of the mass must necessarily be in the common direction in which the particles are constrained to move, by virtue of the external conditions to which the whole glacier is subjected. This, in fact, belongs to the definition of "differential motion" as I understand the term; nor can I conceive how any mechanical effects, such as dislocation or bruising, can be attributed to a "differential motion" in any arbitrary or conventional sense, rather than to the real relative motion which I understand to be meant by the expression. If so, it appears to me impossible to accept this theory of the veined structure without a far more explicit explanation than any which has yet been given of it. Assuming, then, what I conceive to be the only intelligible and determinate meaning of the above expression, I shall proceed to investigate certain geometrical results which flow from it. Since the investigation is entirely geometrical, we may suppose the surface of the glacier and its longitudinal axis to be horizontal. I shall also suppose the line of motion of every particle to be parallel to that axis, and the velocity to be invariable along each such line, but different for different lines, (1) because the velocity of the central is supposed to be greater than that of the marginal portions of the mass, and (2) because the velocity of its upper is greater than that of its lower surface.

55. Let P (fig. 14) be any particle of the glacier, and let the plane of the paper represent a transverse plane perpendicular to the common direction of all the lines of motion of the component particles of the mass. Also let p be any other particle likewise in the plane of the paper, its distance from P being very small and equal to ρ; i. e. p must lie in the circumference of a circle in the plane of the paper, whose centre is P, and whose radius ρ is extremely small. Our first object will be to determine the relative velocity, or differential motion of P and p, and the positions of p in the small circle when that relative velocity is a maximum, and when it is zero.

For this purpose let the horizontal plane of the base of the glacier be made the plane of xy, and the vertical plane parallel to the longitudinal axis of the glacier, and along its

flank on the left, the plane of xz. The plane of yz will be a vertical transverse plane; let it be represented by the plane of the paper, to which, therefore, the line of motion of every particle will, by hypothesis, be perpendicular. Let P (fig. 14) represent a

Fig. 14.



material point in the plane of the paper, or that of yz. (We take it in this particular plane because we shall not be immediately concerned with the coordinate x.) Let AM$=y$, and MP$=z$. Also, take another point p supposed to be very near P, and let its coordinates be $y+\eta$ and $z+\zeta$, η and ζ being referred to P as origin. Also let V be the velocity of P perpendicular to the plane of the paper, and V$+v$ that of p; V will be some function of y and z; and v a function of η and ζ. As we have chosen the coordinate planes, V will increase with y and z, because the centre of the mass moves faster than its sides, and the upper moves faster than the lower surface; and for the like reasons, v will increase with η and ζ. Now since η and ζ are very small, we may consider any increase of v, due to an increase of η, as $=\mu\eta$, and an increase due to that of ζ, as $=\mu'\zeta$, where μ and μ' are functions of y and z, but independent of η and ζ. They express the rate at which V increases as we pass from P to contiguous points in the plane of the paper, and in directions parallel respectively to the axes of y and z. We shall then have

$$v=\mu\eta+\mu'\zeta;$$

or if

$$\eta=\varrho\cos\theta,$$
$$\zeta=\varrho\sin\theta,$$
$$v=\varrho(\mu\cos\theta+\mu'\sin\theta).$$

From what has been above stated, this quantity must be a maximum with respect to θ, considering μ, μ', and ϱ* as constants. This gives

$$-\mu\sin\theta+\mu'\cos\theta=0.$$

* The tendency of the tangential differential motion of two particles very near together, to bruise or dislocate the mass, will manifestly depend on the contortion or twisting produced by this relative motion, and therefore on the angular change of position of the line joining the two points. Thus, in fact, $\frac{v}{\varrho}$ is the quantity to be really made a maximum. This is equivalent to considering ϱ constant in differentiating as in the text.

Let θ_1 and θ_2 be the two values of θ which satisfy this equation; then

$$\tan\theta_1 = \tan\theta_2 = \frac{\mu'}{\mu};$$

and

$$\theta_2 = \tan^{-1}\frac{\mu'}{\mu} + 180°.$$

From the above expression for v, θ_1 gives v a positive value, and θ_2 the same numerical value with an opposite sign, the one being the algebraical maximum value, the other the minimum one.

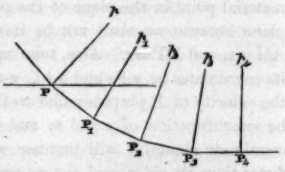
Moreover, we see from the above value of v, that $v=0$ when

$$\tan\theta = -\frac{\mu}{\mu'} = -\cot\theta_1,$$

which shows that the angular distance between the directions in which v is respectively a maximum and zero, is equal to a right angle.

56. To interpret these formulæ, draw P p (fig. 15) making the angle $\tan^{-1}\frac{\mu'}{\mu}$ with the axis of y. The relative velocity for p and P will be greater than for any other point at the same distance from P. Draw P P_1 perpendicular to P p, taking P P_1 very small; then since $v=0$ in the direction at right angles to P p (by the last equation), the velocity of P_1 will equal V, that of P. At P_1 (since it is nearer the central axis of the glacier than P) the *rate* of increase of V, as depending on y, will be less than at P, and therefore μ will also be less (art. 55); and for a like reason* (since P_1 is nearer the lower surface than P) μ' will be increased. For both these reasons $\theta\left(=\tan^{-1}\frac{\mu'}{\mu}\right)$ will be greater at P_1 than at P. Draw $P_1 p_1$ accordingly. Again, draw $P_1 P_2$ perpendicular to $P_1 p_1$, making $P_1 P_2$ very small. The velocity of P_2 will still $=V$, and the relative velocity of p_2 and P_2 will be a maximum in the same sense as before. We may proceed in the same manner with any number of points. Now, when we pass to the limit, by taking P P_1, $P_1 P_2$, &c. indefinitely small, the locus of P $P_1 P_2$, &c. will become a continuous curve, possessing the dynamical property, in the case of a glacier, that each of its particles moves with the same velocity perpendicular to the plane of the paper, and they have consequently no tendency to separate from each other.

Fig. 16.



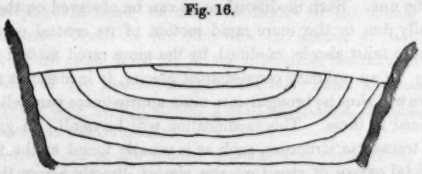
Again, taking ϱ indefinitely small, we shall have another continuous curve $p p_1 p_2$, &c. contiguous to the former, and so related to it that the relative velocity of two particles situated respectively on these curves, and on a common normal to them, will be a

* The increase in the *rate* at which V increases as we descend from one longitudinal line of motion to another, cannot be made a matter of observation, but the analogy with the variation of V in passing from the axis of the glacier to its sides (in which case we know that the *rate* of variation increases) would seem fully to justify the assumption. The conclusion of the text, however, is not dependent upon it.

maximum, and will consequently have a maximum tendency to separate from each other by their differential motion. I have spoken here of physical *points* as perhaps conveying more distinctly the idea of the intervening distance denoted by ϱ. I might have equally spoken of indefinitely small elements of determinate forms, considering ϱ as the distance between their centres of gravity. These are only different kinds of phraseology by means of which we reason on the ultimate elements of which a continuous mass must be constituted.

In the above investigation the velocity of each particle has been assumed to be the same at every point along its line of motion. Consequently whatever holds for the motions with which these particles pass through one transverse plane, will hold with respect to any other such plane. Consequently there will be two contiguous cylindrical surfaces generated by lines parallel to those of the motion of the glacier, and having for their directors the two contiguous curves above described on the plane of yz; and the motion of the particles in these cylindrical surfaces will have the same dynamical characters as those above enunciated for the particles in the two guiding curves. There will be an indefinite number of such surfaces following the same law. A section of the mass, made by a transverse vertical plane parallel to that of yz, will be represented by fig. 16. Each surface will be perpendicular to this transverse plane.

Fig. 16.



This system of surfaces would necessarily result from the differential motion in the sense in which I regard it; nor can I conceive how the veined structure can originate in that motion, in the way in which the author of the theory appears to consider it to originate, unless the veins should coincide with the surfaces here investigated. In such case every line of structure on the surface of the glacier, in the typical case above considered, would coincide with a line of motion, and would therefore be parallel to the axis and sides of the glacier. In the central parts of the glacier, where the variation of V for different points situated on a transverse horizontal line is usually very slow, μ will be very small, and therefore $\theta\left(=\tan^{-1}\frac{\mu'}{\mu}\right)$ will nearly equal 90°. Consequently the structural surfaces will be very nearly horizontal. In the marginal portions of the glacier these surfaces will meet the superficial surface of the mass at angles

$$=90°-\theta=90°-\tan^{-1}\frac{\mu'}{\mu},$$

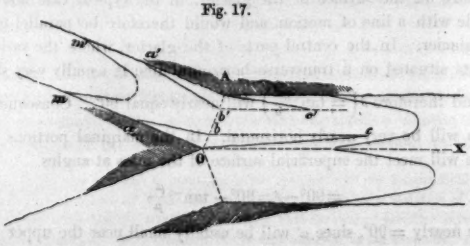
which will be nearly $=90°$, since ω' will be usually small near the upper surface, and μ

will be comparatively large near the sides of the glacier. The superficial curves of structure would be all straight lines parallel to the axis of the glacier.

In actual glaciers, the forms of the curves of structure on the outer surface would be modified by the fact of the unequal thinning of the glacial mass in consequence of the more rapid thawing towards its lower extremity, so that the existing external surface is no longer parallel to the longitudinal lines of motion. Consequently the outer surface would intersect the internal structural surfaces obliquely, and the superficial curves of structure would be changed from straight parallel lines to very elongated loops, but would never approximate to straight transverse lines, as they always do at the foot of an ice-fall. We may also observe that there could be no longitudinal development of veins along the axis of the glacier, as the immediate result of differential motion. Such veins could only exist by transmission, as will be explained in the next section, where I shall revert to the forms of the surfaces of greatest differential motion which have been here investigated.

57. *Modification of the Veined Structure arising from the Motion of the Glacier.*—I now proceed, according to my intention as above expressed (art. 47), to examine the modifications produced by the general motion of a glacier, on the forms and positions of the lines and surfaces of structure as originally produced by the immediate action of the causes to which they may be due. Such modifications as can be observed on the surface of a glacier, are principally due to the more rapid motion of its central portion; the interior surfaces of structure must also be modified by the more rapid motion of the upper surface of the mass. In an ordinary canal-shaped glacier, it is manifest that the marginal curves of structure will thus be brought into more approximate parallelism with the sides, if originally inclined to them. This modification will be small. A greater one will be produced in the transverse structure, such as is usually found at the foot of an ice-fall. There the superficial curves of structure run almost directly across the glacier, by the motion of which they will be transformed into elongated curves, at distances from the fall sufficiently great, the elongation increasing with that distance. In a glacier, like the Aar, formed by the junction of two great tributaries, the modification of structure below their confluence will be more complicated. Let fig. 17 represent the glacier as

Fig. 17.



before, and let ab, $a'b'$ be two lines of marginal structure, representing the two systems of lines to which they respectively belong. A particle in the tributary glacier will move parallel to the side of the glacier till it arrives, for instance, at b, a point near the section O A, and will afterwards move parallel to the axis O X. When the particle at a arrives at O, suppose the particle which was simultaneously at b to have arrived at c, bc being parallel to O X; then will O c be the position in the united glacier of the physical line of structure which before occupied the position ab. But the velocity with which a particle will move from b to c in the central part of the united glacier, will be considerably greater than that with which a particle will move from a to O along the side of the tributary. Consequently the distance bc will be considerably greater than ab, and O c will make a proportionately smaller angle with O X than ab makes with the side aO of the tributary. Hence, if the lines of marginal structure approximate to parallelism to the sides in the tributary, the same lines, forming those of the longitudinal structure in the central portion of the united glacier, will approximate still nearer to parallelism with each other and with O X. Subsequently this approximation to parallelism will decrease, since a particle will move rather faster along O X than along bc; but assuming always that the divergency is small in the marginal structure of the tributary, a simple calculation shows that it will not become considerable in the united glacier except at distances from the junction equal to many multiples of the whole breadth of the glacier*. Such, at least, would be the case with the glacier of the Aar. If, on the contrary, the lines of marginal structure in the tributaries should make a considerable angle with the sides of the glacier, they would also make a considerable, though smaller angle with the axis of the united glacier, and their inclination to that axis would afterwards increase more rapidly.

Taking the opposite flank of the glacier, suppose two particles on the same line of structure to be simultaneously at a' and b'; and reasoning as before, suppose b' to have moved parallel to the side of the united glacier to c' while a' moves to A. Then will A c' be the resulting position of the *same* line of structure as previously occupied the position $a'b'$. In this case, however, $b'c'$ will be nearly equal to a'A, since the velocities along the margins of the combined glacier and the tributaries will probably be much the same. Hence the directions of the marginal lines of structure with reference to the sides of the valleys, will be less changed than those of the longitudinal structure with reference to the axis O X.

I have above supposed the absence of any transverse lines of structure on the central portion of the tributary glaciers. If, however, they exist so as to complete the loops of the curves (mm') (fig. 17), they will of course also exist, by the transmission we are here assuming, in the combined glacier, in the forms of similar loops, as represented in the figure.

58. If we compare the forms of the marginal structural curves in a canal-shaped glacier (represented in fig. 7, art. 42), resulting from the immediate action of the forces

* This calculation is founded on data supplied by M. Agassiz in his 'Système Glaciaire,' p. 451.

producing them, it is evident that it will generally be difficult or impossible to recognize by observation the modification which may have been produced in them by transmission. The case of structure represented in fig. 9 (art. 45), if the real structure in a glacier were sufficiently developed and carefully observed, would afford a test as to whether the forms were original, or had been modified by transmission; for, in the latter case, the loops would never change by elongation into an absolutely longitudinal structure as represented in the figure referred to. But this test is far, at present, from being a practical one. Again, in the glacier of the Aar, if the structure were perfectly developed, it would afford us the required test, as is easily seen by comparing fig. 17 and its completed loop in the main glacier, as transmitted from the tributary, with fig. 11 and the lines of longitudinal structure in the main glacier. If the glacier exhibited either of these structures complete, it would testify at once to the point in question. I am not aware, however, that the structure, to whatever cause it may be due, is sufficiently developed, or has been observed with sufficient care, to afford any positive testimony on the subject. The glacier of the Rhone, also, fails to afford us a practical test on this point; for the curves of structure may there be accounted for either by supposing them instantaneously formed or transmitted from the fall where they originate.

The supposition that the structural surfaces, at points of a glacier remote from the place at which they commence, are merely the effects of transmission, involves the conclusion that the veined structure can only be originally formed under enormous pressure (according to the pressure theory), like that at the bottom of an ice-fall, and that, when once formed, it is difficult to obliterate. In this case it would seem that the transverse curves of structure formed at the bottom of a fall ought to be distinctly preserved at a distance from it, as elongated loops extending completely across the glacier. I am not aware how far they are so, either in the case in which they proceed from the Talèfre fall, for instance, on the Mer de Glace, or from that of the Géant. The glacier of La Brenva above cited (art. 49) seems to afford an example of the instantaneous generation of the veined structure under a pressure which may not be comparable with that immediately below the junction of the Aar tributaries; and this same example at La Brenva seems also to afford an instance of a comparatively sudden obliteration of the structure where the immediate cause of it ceases to act. We may also remark that the marked and increased development of the longitudinal lamination along the central moraines proceeding from the junction of two considerable glaciers, appears to indicate the local efficiency and instantaneous effect of the causes of the structure. But particular cases of this kind require to be examined with greater accuracy of detail before we can derive from them any reliable inferences. It would seem most probable that the structure in any particular locality may frequently be due partly to the instantaneous action of physical causes, and partly to transmission. The question well deserves the consideration of those glacialists who may interest themselves about this curious structure of glacial ice, and the physical and mechanical causes to which it may be due.

I may make another remark on this doubtful question. The *dirt-bands* of the Mer de Glace, if Dr. TYNDALL's views respecting them should be proved to be correct, may afford the means, supposing their forms and positions sufficiently determinate, of deciding how far the loops of structure in the middle and lower parts of the glacier may be merely the original transverse curves at its upper end, modified by transmission, or may be attributable to the great transverse pressure to which that glacier must be subjected at certain points of its course. If the dirt-bands are entirely formed at the upper part of the glacier and are there coincident with the curves of transverse structure, and if they also remain coincident with them at distant points of the glacier, then, since the dirt-bands must necessarily be transmitted forms, the curves must almost necessarily be so likewise. Principal FORBES's theory of the dirt-bands would not lead to the same conclusion.

59. *The Pressure Theory and the Differential Motion Theory of the Veined Structure compared.*—The pressure theory of the veined structure, so far as it asserts the perpendicularity of such surfaces to the directions of maximum pressure, appears to be in perfect accordance with observed facts and mechanical deductions, whether the structure be marginal, transverse, or longitudinal. The transversal directions and approximate verticality of the structural surfaces at the bottoms of ice-falls, and the general existence of the structure wherever the glacier must, from the conditions under which it is placed, be subject to great pressure, are also perfectly consistent with this theory. We may also remark that the evidence of facts in favour of it is in a great measure independent of the degree of efficiency which may ultimately be attributed to the transmission of the structural forms. I am not, indeed, aware of any leading observed facts of the veined structure inconsistent with this theory.

With respect to the Differential Theory, the whole of the mechanical reasoning on which it is based is professedly popular, vague, and undemonstrative, and, I believe, as erroneous as such reasoning must almost necessarily be in cases as intricate as those which glaciers present to us, unless it be guided by an accurate conception and a careful analysis of problems which admit of more or less accurate solution, and are typical of those presented to us in nature. In the marginal structure, this theory could never agree with any very sensible deviation in the directions of the superficial curves of structure from parallelism with the sides of a canal-shaped glacier. The attempt to correct this defect by means of what has been called the Ripple Theory, will not now, I imagine, be maintained by any glacialist. The constant existence of the veined structure under great pressure, and its comparative absence where such pressure cannot exist, are left by this theory without satisfactory explanation. It fails altogether to assign any direct cause for the great development of the longitudinal structure along the central moraine of compound glaciers like the Aar; for along the axes of such glaciers there cannot possibly be any differential motion which could produce it. The only structure which could there exist must be a transmitted structure.

But the most conclusive objection to the differential theory is to be found, as I believe,

in its total inability to account for the highly developed structural surfaces, their nearly vertical positions, and approximate perpendicularity to the axis of the glacier, at all points not far from its surface, and near to the bottom of an ice-fall (art. 56). It appears to me inconceivable that any physical or mechanical effect (such as the lamination in question) really and primarily due to the difference of motion of contiguous particles should not manifest itself, if seen at all, in those directions in which the actual difference of motion is greatest. Assuming the truth of this conclusion, the structural surfaces must necessarily be such as above represented (art. 56). The investigation of the forms and positions of these surfaces depends only on the recognized motion of the glacier, and geometrical reasoning in which there can be no ambiguity. Now superficial curves of structure at the bottom of an ice-fall, as thus theoretically determined, are extremely elongated loops (art. 56); whereas it is one of the best-established of glacial phenomena that the actual superficial lines of structure at the foot of an ice-fall are nearly straight and perpendicular to the axis of the glacier. I maintain, therefore, that it is altogether impossible that the differential theory can be true, unless the expression "differential motion" has a very different meaning from any which I have been able to attribute to it*. On the contrary, the pressure theory, so far as it asserts the perpendicularity of the structural surfaces to the lines of maximum internal pressure, appears to be in accordance with all the observations which have yet been made on the subject.

Section VI.—*On the Intensity of the Forces employed in dislocating and crushing the masss of a Glacier.*

60. We have seen that, according to the Pressure Theory, when a glacier is brought into a constraint which it can no longer resist, its structure, or the continuity of its mass, must be destroyed in one of the three ways already specified (art. 28). It would seem probable that this is frequently effected by the crushing of the mass, the structure being immediately restored by regelation. But here arises the question, Whence do the internal pressures and tensions derive sufficient intensity to produce these crushing effects? The enormous weight of the mass of a glacier at once presents itself as the cause of the required intensity. But suppose, after the glacier has been broken and crushed, it should be instantaneously restored to perfect continuity of crystalline structure under the pressure to which, in any part, it may at the moment be subjected; why should the pressure, apparently the same as that under which it had, the instant before, regained its crystalline structure, again destroy the continuity of that structure? The highest mountain does not *crush* the strata which form its base. Again, the superincumbent weight can only produce any great effect at depths sufficiently great, whereas the effects of the internal pressures and tensions are exhibited in the most superficial

* With respect to Principal Forbes's conclusion, that a nearly horizontal force at the bottom of an ice-fall will produce a differential motion in nearly a vertical direction, I can only say that it appears to me so obviously opposed to the simplest conception of the action of such a force, as to be entirely inadmissible. It is unquestionably opposed to all accurate mechanical investigation on the subject (art. 53).

portions of the glacier, where the superincumbent weight can have no very sensible influence. These questions may be partly answered by a careful consideration of the theoretical explanations which have been given in the preceding pages; but for their complete answer they require, I conceive, the recognition of a kind of motion which has been till recently so entirely neglected. I allude to the motion by which a glacier *slides* over the bed on which it reposes (Sect. II. art. 7). I shall shortly proceed to explain the influence of this motion on the intensities of the internal pressures and tensions.

Principal Forbes was struck with this difficulty respecting the adequacy of the internal forces to produce the crushing effects ascribed to them, and the consequent mobility of the component particles *inter se*, though, regarding ice as viscous, the difficulty may naturally be supposed to have appeared less to him than if he had regarded it as a solid substance. He puts the difficulty in the following form*:—"Were a glacier composed of a solid crystalline cake, fitted or moulded to the mountain bed which it occupies like a lake tranquilly frozen, it would seem impossible to admit such a flexibility or yielding of parts as should permit any comparison to a fluid or semifluid body transmitting pressure horizontally, and whose parts might change their mutual position, so that one part should be pushed out whilst another remained behind." The difficulty as thus stated is equivalent to that above mentioned. Principal Forbes meets it as follows:—"But we know in point of fact that a glacier is a body very differently constituted. It is clearly proved by the experiments of Agassiz and others, that a glacier is not a mass of ice, but of ice and water, the latter percolating freely through the crevices of the former to all depths of the glacier; and as it is a matter of ocular demonstration that these crevices, though very minute, communicate freely with one another to great distances, the water with which they are filled communicates force also to great distances, and exercises a tremendous hydrostatic pressure to move onwards, in the direction in which gravity urges it, the vast porous crackling mass of seemingly rigid ice in which it is, as it were, bound up.

"Now the water in the crevices does not constitute the glacier, but only the principal vehicle of the force which acts on it; and the slow irresistible energy with which the icy mass moves onwards from hour to hour with a continuous march, bespeaks of itself a fluid pressure. But if the ice were not in some degree ductile or plastic, this pressure could never produce any, the least, forward motion of the mass. The pressures on the capillaries of the glacier can only tend to separate one particle from another, and thus produce tensions and compressions, *within the body of the glacier itself*, which yields, owing to its slightly ductile nature, in the direction of least resistance, retaining its continuity, or recovering it by reattachment after its parts have suffered a bruise, according to the violence of the action to which it has been exposed." The author again remarks (p. 167), "If it were not for the capillarity of the ducts, it is plain that no effective hydrostatic pressure could be developed at all; the flow being equal to the supply, no part of the *vis viva* would be expended in producing internal pressures."

* Occasional Papers, p. 165. See also a memoir in the Transactions of the Royal Society for 1846, Part III.

61. The author of the preceding extracts would appear, I think, to have somewhat mistaken the nature of the problem to be solved. He asserts that if a glacier were traversed by a great number of small tubes or ducts filled with water, an *enormous hydrostatic pressure* would be the consequence. Now it is absolutely necessary for me to examine strictly the correctness of this conclusion; for, if it be true, it would be useless to seek for any cause which should give efficiency to the internal pressures, besides the hydrostatic pressure to which it is here attributed. I shall show, however, that this conclusion is not correct, and that the efficiency of the dislocating forces is derived, as above intimated, from the sliding movement of the glacier. The existence of the above assumed capillary ducts, as pervading the more compact parts of a glacial mass, appears to be rendered doubtful by the experiments of Professor HUXLEY*, though the observations of M. AGASSIZ undoubtedly prove their existence in certain superficial portions of the glacier of the Aar. But waiving any doubt of this kind, let us suppose the interior of a glacier completely pervaded by these tubes or ducts, extremely small, but sufficient to allow fluid pressure to be communicated freely through them, as Principal FORBES has assumed. When the supply at the upper surface of the mass is regular, the motion of the fluid will become *steady*; and such I shall suppose it to be in the typical case I propose to analyse. We may first confine our attention to a single tube. Suppose the area (ω) of its transverse section at any point P to be variable, but always very small, and δs to denote the length of a small element of the tube; then will $\omega\delta s$ be the volume of the element, and, if the density of the water be denoted by unity, it will also represent the mass of the water in the element δs of the tube. Let the velocity at P, any point in the tube, be v, which I shall assume to be the same for each particle in the section (ω). The motion will be retarded by the *friction* of the sides of the tube; let $f\omega\delta s$ be the retarding force on the element at P. Also let p be the fluid pressure at P; and let the coordinates x, y, z of that point be taken as heretofore; then will z be very nearly vertical, and we shall have, resolving gravity in the direction of the tube,

$$\omega\delta p = g\,.\,\omega\delta s\,.\,\frac{dz}{ds} - f\,.\,\omega\delta s - \frac{d^2s}{dt^2}\,.\,\omega\delta s,$$

or

$$\delta p = g\delta z - f\delta s - \frac{d^2s}{dt^2}\delta s;$$

or, since the motion, by hypothesis, is steady,

$$\frac{d^2s}{dt^2} = v\frac{dv}{ds},$$

and therefore we have

$$p + C = gz - \int f ds - \tfrac{1}{2}v^2.$$

Let p_1, z_1, s_1 and v_1 be the values of p, z, s, and v at the point where the tube meets the surface of the mass. Then

$$p = p_1 + g(z - z_1) - \int_{s_1}^{s} f ds - \tfrac{1}{2}(v^2 - v_1^2), \quad \ldots\ldots\ldots \quad (1.)$$

where p_1 is the atmospheric pressure.

* See Dr. TYNDALL's 'Glaciers of the Alps.'

Also, since the same quantity of the fluid must pass through each transverse section of the tube in the same time, we must have

$$v\omega = v_1\omega_1,$$

and therefore

$$\tfrac{1}{2}(v^2 - v_1^2) = \frac{v^2}{2}\left(1 - \frac{\omega^2}{\omega_1^2}\right).$$

Let us interpret the above equation in different cases. We may first suppose the absence of all friction as a retarding force. We shall then have

$$p = p_1 + g(z - z_1) - \frac{v^2}{2}\left(1 - \frac{\omega^2}{\omega_1^2}\right);$$

and if the section (ω) of the tube do not contract so rapidly as to impede the motion of the water, the velocity acquired at the depth z will equal that of a body projected with velocity v_1, and falling freely by the action of gravity through the space $z - z_1$. We shall therefore have

$$\tfrac{1}{2}(v^2 - v_1^2) = g(z - z_1),$$

and therefore $p = p_1$ the atmospheric pressure, as if the tube were occupied by air. The least value of ω^2 for any value of z in this case will be given by

$$\omega^2 = \frac{v_1^2}{v^2}\omega_1^2$$

$$= \frac{v_1^2}{2g(z - z_1)} \cdot \omega_1^2.$$

If ω satisfy this condition for all values of z, the column of fluid will just fill the tube without its motion being impeded, while the pressure on the tube, as just shown, will be the atmospheric pressure p_1. But suppose ω to decrease, below a given section (Q), more rapidly as a function of z than is implied in the above equation. The motion of the fluid above the section Q would manifestly be retarded, and the retardation could only be due to the upward fluid pressure at Q being greater than the atmospheric pressure p_1 at the top of the tube. In like manner the increased downward fluid pressure at Q would accelerate the motion of the fluid immediately below that section. Any number of similar variations of ω, with consequent variations of velocity and fluid pressure, might take place, subject to the above condition that the tube shall always be full. The fluid pressure at any point cannot be less, but may be greater than p_1.

In this reasoning the tube is supposed to be independent of any other; but now suppose it to be confluent with a second and similar tube. At the point of junction we must have the condition that the pressures in the two tubes must be equal. This condition will be always satisfied, at whatever points in the surface of the mass the tubes may originate, provided each tube be such that the fluid pressure in it (as in the first case above explained) shall be equal at every point to the atmospheric pressure p_1. In such case water might pass from the upper surface through the mass, along any number of smooth tubes like those above described and communicating freely with each other.

The pressure in any tube would cause no reflux of the water, or other disturbance in a confluent one, because the pressures in them would be equal; but it must be carefully observed that there would, in this case, be no internal fluid pressure greater than that of the atmosphere, and therefore none capable of producing any effect in expanding the general mass, and urging it onwards. But if, on the contrary (as in the second case above explained), the tube be such that the pressure in each tube considered separately should be greater than p_1, the condition of an equality of pressure at the point of confluence of any two tubes would not be generally satisfied, and the whole motion would be interfered with. If the pressure p in any number of tubes became great, it would manifestly produce a reflux in any confluent tube in which the pressure was smaller, and a consequent outpouring of water from every pore and crevice on the surface of the lower regions of a glacier. Such, in fact, must necessarily be the case wherever there is an internal fluid pressure much exceeding that of the atmosphere, and where all parts of the mass are permeated by ducts of any kind through which water can flow out of the mass with little impediment.

Hence it appears that if the internal ducts were such as not to impede the currents passing through them by means of friction, or any kind of capillarity, there might indeed be large internal pressures, but they would necessarily be accompanied by overflowings from the superficial pores and crevices in many parts of a glacier. But such a phenomenon would be entirely opposed to all observation; and it is this which constitutes the proof that there can be no great fluid pressure in the interior of a glacier due to water contained within it in tubes which exert no sensible retarding effect by friction on the water running through them. This conclusion agrees with that expressed by Principal Forbes in the last of the preceding extracts; but the reason assigned is very different. The absence of great fluid pressure within the glacier in such case is not due to the absence of capillarity, but to the particular condition of its ducts and crevices being open in every part of the bounding surface of the mass. There can be no expenditure of *vis viva* in producing pressure on a *smooth* surface, as is well known, though such pressure must necessarily be produced in the case before us, as in all cases of constrained motion when the constraint is produced by the action of such surfaces. The fact of no *vis viva* being lost does not imply that no internal pressure would be produced.

62. But let us now turn to the far more important case in which the passage of the water through the small ducts of any mass, as that of a glacier, is impeded by the friction of the sides of the ducts. It follows, as shown in the preceding explanation, that, since in actual cases there is no overflowing of water from the pores and crevices, here assumed to pervade one part of the mass as well as another, the fluid pressure in all confluent ducts at the point of confluence must be the same, and, therefore, independent of the height above that point at which each duct may meet the external surface of the glacier. This pressure, when the surface is exposed to the atmosphere, can be only the atmospheric pressure. Hence it follows in this case, as in the previous one, that there can be no internal fluid pressure greater than that of the surrounding

atmosphere, and such, therefore, as can exert any influence in expanding the mass, and promoting its onward motion. It will act on the interior of the mass in directions *normal* to the tubes. But there is another force also, friction, acting on the mass of the glacier in this case, in directions *tangential* to the tubes, the magnitude of which requires to be considered. It retards the motion of the fluid, acting equally on the fluid and on the sides of the tubes containing it in opposite directions. Now in the case before us, $p=p_1$, the atmospheric pressure, and, therefore, by equation (1.), art. 61,

$$\int_{s_1}^{s} f ds = g(z-z_1) - \tfrac{1}{2}(v^2 - v_1^2);$$

and differentiating,

$$f = g\frac{dz}{ds} - \tfrac{1}{2}\cdot\frac{dv^2}{ds},$$

and

$$\int_{0}^{s_1} f\omega ds = \int_{0}^{s_1} g\omega ds\cdot\frac{dz}{ds} - \tfrac{1}{2}\int_{0}^{s_1}\frac{dv^2}{ds}\cdot\omega ds, \quad \ldots\ldots\ldots \quad (2.)$$

where $\int_{0}^{s_1} f\omega ds$ is the whole retarding force of friction in any one of the tubes whose length $=s_1$ (art. 61), and is therefore the amount of friction produced by the water on the sides of the whole tube.

To find the value of the last term in equation (2.), we have (the duct being always full)

$$v\omega = v_1\omega_1, \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3.)$$

where ω_1 is the value of ω when $s=0$ and $v=v_1$. Therefore

$$v^2 = \frac{v_1^2\omega_1^2}{\omega^2},$$

$$\frac{dv^2}{ds} = -\frac{2v_1^2\omega_1^2}{\omega^3}\cdot\frac{d\omega}{ds},$$

$$\frac{dv^2}{ds}\omega\partial s = -\frac{2v_1^2\omega_1^2}{\omega^2}\cdot\partial\omega,$$

and

$$\int_{0}^{s_1}\frac{dv^2}{ds}\omega\partial s = 2v_1^2\omega_1^2\left(\frac{1}{\omega_2} - \frac{1}{\omega_1}\right).$$

Now we may venture to assert that when water descends through exceedingly minute ducts in the manner here supposed, the velocity with which it will permeate the lower portions of the mass will be much the same as that with which it will pass through the upper portion. Assuming this, we shall have by equation (3.) $\omega_2=\omega_1$, and the value of the above definite integral will $=0$. Hence, by equation (2.), we have

$$\int_{0}^{s_1} f\omega ds = \int_{0}^{s_1} g\,.\,\omega ds\,.\,\frac{dz}{ds};$$

$g\omega ds$ is the weight of an element of the water in the tube, and $g\omega ds.\frac{dz}{ds}$ is a force less than that weight. Consequently the definite integral on the right-hand side of the last

equation expresses a force *less* than the weight of the whole fluid contained in the tube; and if we call this last weight W_1, that equation shows that the entire effect of the friction, estimated in the tangential direction in which it acts at each point of the tube, is less than W_1.

Again, let δX_1 be the part of the friction on any element of the tube, resolved parallel to the axis of x; then

$$\delta X_1 = f\omega ds . \frac{dx}{ds},$$

$$X_1 = \int_0^{s_1} f\omega ds . \frac{dx}{ds} = \int_0^{s_1} g\omega ds . \frac{dx}{ds} . \frac{dx}{ds};$$

similarly, we have

$$Y_1 = \int_0^{s_1} f\omega ds . \frac{dy}{ds} = \int_0^{s_1} g\omega ds . \frac{dx}{ds} . \frac{dy}{ds},$$

$$Z_1 = \int_0^{s_1} f\omega ds . \frac{dz}{ds} = \int_0^{s_1} g\omega ds . \left(\frac{dz}{ds}\right)^2.$$

Since $\frac{dx}{ds}$, $\frac{dy}{ds}$, and $\frac{dz}{ds}$ are each less than unity, it follows that X_1, Y_1, and Z_1 are each less than W_1; and if, taking all the tubes,

$$X = X_1 + X_2 + \&c., \quad Y = Y_1 + Y_2 + \&c., \quad Z = Z_1 + Z_2 + \&c., \quad W = W_1 + W_2 + \&c.,$$

we shall have X, Y, and Z each less than W, the weight of water in the whole mass of the glacier.

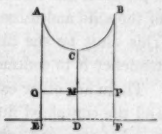
The internal pressure Z will tend to elevate the upper surface of the glacier; the pressure Y will be equilibrated by the pressures on the opposite flanking walls of the glacial valley. To interpret the meaning of X, we may suppose the vertical section of the glacier near its origin to be immoveable; then will the pressure X tend to urge onwards the whole mass in the direction of the containing valley, where there is no barrier to oppose its action.

To form a conception of the magnitudes of the pressures X, Y, Z, we may remark that the water in our supposed tubes must almost necessarily descend through the mass in approximately vertical directions. Admitting this supposition, $\frac{dz}{ds}$ will nearly equal unity, and Z_1 will nearly equal $\int_0^{s_1} g\omega ds$, or nearly the weight of the fluid contained in the single tube. Consequently the whole vertical resolved part of the friction=Z= approximately the whole weight of the fluid contained in the glacier. Y will be equal only to a small portion of W, because $\frac{dy}{ds}$, in the case we have taken, will be very small; and X will be also very small, because $\frac{dx}{ds}$ will be so. And thus it follows that the whole internal pressure, arising from the friction on the sides of the small ducts through which the water descends, and tending to urge the glacier forwards, cannot exceed a small fraction of the weight of the water descending through its pores, and this latter weight again must doubtless be an exceedingly small fraction of the weight of the glacier.

63. It appears, then, from these explanations, that there will be at every point (P) of every duct, two internal forces, the fluid pressure p acting normally, and the friction acting tangentially at that point on the sides of the tube. But assuming these small ducts to pervade the superficial as well as the inner portions of the mass, the fluid pressure p can never much exceed the atmospheric pressure, which, acting externally, will very nearly counterbalance it; and this will be true whether the motion of the water in the ducts be impeded by friction or not. Also the whole resolved part of friction acting on the ducts, in the direction of the general motion of the mass, must be very small compared with the weight of the whole percolating fluid. Neither of these forces, therefore, can have any sensible influence in augmenting the onward motion of a glacier, compared with other forces which, as I shall shortly explain, tend to produce that effect.

64. In the preceding explanations I have spoken of the retardation of the motion of a fluid in small ducts, as due to friction rather than capillary action. Capillarity, when it exhibits itself in the form under which it is more usually contemplated, acts in a manner totally different to that in which friction acts. We know that a column of water, or of other fluids, of a certain length may be supported in a vertical tube of sufficiently small bore, by the attractions between the particles of the fluid, and the attraction between the fluid and the tube. These attractions produce the capillarity of the tube. If, however, the tube be perfectly full, whether the fluid be at rest or in motion, its capillary action on the fluid will counteract itself, and will produce no effect sensible to observation. It is only when the tube is partially empty that a part of the capillary action on the contained fluid is uncompensated, and exhibits itself in the column of fluid which it is capable of supporting. These partially empty tubes cannot properly belong to a system of tubes, like those of a glacier, which serve as *ducts* through which the water is constantly running, and which must therefore be constantly full; at all events, the number of tubes exhibiting the effect of capillarity as above described must probably be extremely rare in a system of ducts like those of a glacier. Supposing such tubes, however, to exist, we proceed to explain their effect in producing internal pressure.

Fig. 18.



Let A E F B be a section of the capillary tube made by a plane through its axis, the tube being considered cylindrical and vertical. Let E D F be the level of the surface of the external fluid, which we may suppose to be water, and into which the lower end of the tube is placed. Also let A C B be a section, by the above plane, of the surface of the water maintained in the tube by capillary action. Our object is to ascertain whether this water will produce any pressure on the sides of the tube tending to thrust them outwards, and thus produce an expansion of a solid mass in which any number of such capillary tubes might exist.

For this purpose we must consider how the column of water in the tube is supported.

Now, manifestly, the atmospheric pressure, acting equally in all directions, can contribute nothing to this effect; nor can there be an upward pressure on the base E F of the raised column of water; for the pressure at any point of that base can only be equal to that at any point in the surface of the external fluid, which, neglecting the pressure of the atmosphere (as we may do from what has just been stated), will be zero. Again, the resultant attraction of the tube on any single particle of the fluid must be in a direction perpendicular to the surface of the tube, and must therefore be horizontal. Consequently it can produce *directly* no force on the particle or on the whole mass of the fluid column in a vertical direction. The direct effect of gravity, on the contrary, is to drag the whole column of water downwards, and the leading point in the problem of capillary action is to explain how this tendency of gravity is counteracted.

In a question like this, which is merely subsidiary to the general problem treated on in this paper, it must suffice that I quote those results which are familiar to every one acquainted with the ordinary investigations respecting capillary action. Now it is shown by such investigations that the fluid column A E F B is supported (so far as regards any vertical action upon it) in the same manner *as if* it were suspended freely from an infinitely thin and perfectly flexible membrane accurately coinciding with the actual surface A C B, the particles of the fluid being supposed to adhere to the membrane and to each other by virtue of the cohesion or attraction between them, without which, in fact, the ordinary phenomena of capillarity could not exist.

If the column of water in the tube were entirely supported by an upward pressure on its base E F, then would gravity produce a *pressure* on any horizontal section Q M P, the whole amount of which would be the weight of the portion of the column above it, and there would be a corresponding *pressure* on the inner surface of the tube at P and Q, tending to push it *outwards*; but if the column were supported, as above supposed, at its upper surface, gravity would produce a *tension* at the horizontal plane Q M P, the whole amount of which would be equal to the weight of the fluid between Q P and the base E F. Thus the whole column would be in a state of *longitudinal tension*, and therefore also, by the fundamental property of fluids, in a state of *horizontal tension*—*i. e.* the action between the fluid and the inner surface of the solid tube, instead of being a pressure, must be a *tension*, supported by the mutual attraction between the particles of the solid and those of the fluid, supposing the contact between them not to be broken. This must be the direct effect of gravity in the actual case; and so far, therefore, its tendency is to contract and not to enlarge the diameter of the tube.

There are other causes, however, by which action may be produced between the tube and the contained fluid. First, a *pressure* will necessarily arise from the mutual attraction between the tube and the fluid; but here we have the action of the fluid on the tube, and the reaction of the tube on the fluid, the one tending to pull the surface of the tube inwards, and the other to push it outwards. The action and reaction thus counteract each other, and the pressure thus produced can manifestly have no tendency either to expand or contract the tube.

Again, in any actual case of a fluid sustained in a capillary tube, the inner surface of the tube will not generally be a surface of free equilibrium like the upper surface of the fluid itself; and therefore there must necessarily be some action between the tube and fluid, should they remain in contact, even if there were no attraction, like that just considered, between them. Now it can be shown, according to the fundamental principles on which the theory of capillarity is founded, that in all cases resembling the one we have been considering, the action in question must be equivalent to a *tension* on the inner surface of the tube. Hence this action, as well as that due to gravity, produces forces on the tube which tend to *contract* and not to *expand* it, while the mutual attractions of the tube and fluid produce directly neither the one tendency nor the other. Consequently the general tendency of capillary action in the interior of a glacier will be to contract and not to expand its dimensions. The contrary notion has probably arisen from the idea that gravity would produce a pressure on the interior surface of a capillary tube like that which it produces in a tube of larger dimensions. The fluid which may exist in these capillary tubes will, of course, add its own weight to that of the glacier, an addition probably too insignificant to produce the slightest sensible influence.

65. There is something so plausible at first sight in the idea of a great internal fluid pressure within a glacier, due to the water percolating through it, or suspended within it by capillarity, while additional weight has been given to this notion by the advocacy of the author of the Viscous Theory, that I have thought it essential to enter into more details on the subject than I should otherwise have deemed necessary, in order to prove the fallacy of the conclusions which have been deduced from erroneous views respecting it.

I now proceed to explain how the intensity of the internal forces is increased by the sliding movement of the glacier.

66. *Effect of the Sliding of a Glacier on the Internal Pressures and Tensions.*—It has frequently been objected to the sliding of a glacier, that the inequalities along the sides of the containing valley would effectually prevent such motion. This objection, however, will be entirely obviated, if we eliminate the uncertain and irregular opposing forces arising from local lateral obstacles, by substituting for the sides of the glacial valley two imaginary vertical planes near and approximately parallel to them, so that we shall thus have the tangential action of ice along these planes as the retarding force on the general mass of the glacier, instead of the action of the walls of the valley. The greatest magnitude of this retarding force must be equal to the greatest tangential cohesive power of the ice. This is, in fact, the greatest force which the walls, however irregular, could possibly exercise in opposing the sliding past them of the general mass of the glacier. To simplify our problem as much as possible, I shall also first suppose the glacier of uniform width and thickness, and the inclination of its bed to be likewise uniform. We may then consider A and B each $=0$. I shall also suppose $C=0$, and

$E=0$, as well as $D=0$. We shall thus have (art. 29 (1.)),

$$p_1=F,\quad p_2=-F,$$
$$\tan 2\alpha=\infty.$$

F will vanish along the axis of the glacier, as we have seen, and will have its greatest value along the imaginary vertical planes by which we here consider the moving mass as effectively bounded along its lateral margins. Let its value along these planes be F_1. If we suppose, as we may in this approximation, that every particle in the same vertical line moves with the same velocity, F_1 will be the same for every point of the bounding lateral planes. Moreover, let the tangential action exercised by the bed of the glacier on its lower surface be denoted by f_1. Let us now conceive the mass to be placed in a position of no constraint. It will immediately assume a position of constraint by virtue of its small extensibility, and, provided the internal forces p_1, p_2, and F are insufficient to dislocate the mass along the lateral vertical planes (where their magnitudes will be the greatest), the glacier will be held at rest in its state of constraint by the external forces acting upon it. Now F_1 and f_1 being referred to a unit of surface, if a, b, c be the length, breadth, and depth of the glacier, we shall have

$$\text{The tangential force on each flank} = F_1 ac,$$
$$\text{The tangential force on the bottom} = f_1 ab,$$

and these must be in equilibrium with the weight of the mass on the plane whose inclination is ι. Hence if ω be the weight of a unit of volume of glacial ice, we shall have

$$2F_1 ac + f_1 ab = \omega abc \sin\iota,$$

and

$$F_1=\tfrac{1}{2}\left\{\omega b \sin\iota - f_1 \frac{b}{c}\right\}.$$

Suppose $\overline{F}$ to denote the tangential cohesive power of the mass. Then, if

$$F_1=\overline{F},$$

the glacier will be just on the point of dislocation; and if F_1 exceed $\overline{F}$ in the smallest degree, the mass will be dislocated along the lateral planes and move onwards.

We have shown (art. 8) that the effect of f_1 *to hold the mass of the glacier at rest* is extremely small; consequently it may be neglected in the above equation, and we shall then have

$$F_1=\tfrac{1}{2}\omega b \sin\iota.$$

If the lower surface of the glacier were firmly frozen to its bed, we might have $f_1=F_1$, and therefore

$$F_1=\frac{\omega b \sin\iota}{2+\frac{b}{c}};$$

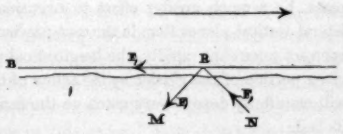
c is properly the depth of the glacier along its flanks, so that $\frac{b}{c}$ may be large.

Hence we see that F_1 may become much greater when f_1 is very small, than if it were

nearly $=F_1$. Consequently F_1 *will be much more likely to attain the magnitude* $\bar{F}$, *sufficient to dislocate the mass, if the glacier slide over its bed as described in art.* 8, *than if it were attached to its bed so as not to slide at all, and its whole motion should be that due to the molecular mobility of its particles alone.*

The above equation expresses the condition of the mass being on the point of dislocation in terms involving the *tangential* cohesion; it will be easy to express it in terms of the *normal* cohesion. Generally, instead of the forces A, B, F acting on any element, we may substitute the forces p_1, p_2 (art. 29), acting in their proper directions as determined by the values of α. Let fig. 19 represent one side of the glacier with the lateral plane B R; then, since at any point (R) in that plane $p_1=F_1$, $p_2=-F_1$, and $\tan 2\alpha=\infty$, we may substitute for F, acting tangentially along R B, two other forces, viz. a tension $=F_1$ along R M, and a pressure $=F_1$ along N R, both directions making angles of 45° with B R. Consequently an equal tension and pressure similarly applied at each point of the lateral vertical planes, would by hypothesis balance the tendency of the mass to descend in the direction B R. Now F_1 acting at an angle θ on B R will produce a force $=F_1\cos\theta$ on a unit of surface of B R. Therefore the tension F_1 acting along R M will produce a force on the same unit, of which the resolved part along R B will

Fig. 19.



$$=F_1\cos 45°.\cos 45°,$$

$$=\frac{F_1}{2}.$$

Similarly, the pressure F_1 along N R will produce a force the resolved part of which along R B will also $=\frac{F_1}{2}$. These together $=F_1$, and the whole supporting force on the two lateral vertical planes will $=2F_1ac$, F_1 being now the measure of a pressure or a tension acting *normally* on a unit of surface. Therefore

$$2F_1ac=\omega abc\sin\iota,$$

and

$$F_1=\omega\frac{b}{2}\sin\iota.$$

Consequently a glacier like that we have been considering, will necessarily be dislocated by its own weight resolved along the plane of its bed, if its normal cohesive power be less than the weight of a column of glacial ice whose transverse section is unity, and whose length = semiwidth of the glacier multiplied by the sine of the inclination of its bed to the horizon. If the glacier were a mile wide and its inclination about 5°, it would be necessary, in order that it should not be dislocated, that its cohesive power should be such that a vertical cylindrical column of glacial ice about 200 feet long should be capable of supporting itself when suspended by its upper extremity. This would be the measure of the greatest tension $p_1(=F_1)$ at any point along either of the

lateral vertical planes, which could be produced under our assumed conditions. If the cohesion were less than this, the mass would necessarily be ruptured in some way or other in its marginal regions. The above, however, is only the lowest limit to which the force F_1 would attain. For let a represent the length of a given portion only of a glacier, such that at the lower transverse vertical section of that portion, the longitudinal *tension* shall be greater than at the higher bounding transverse section, instead of being equal to it as above supposed. It is manifest that F_1 will be increased along the lateral vertical planes of that portion of the glacier. Such will also be the case if the same portion of the glacier be acted on by a longitudinal *pressure* on its higher transverse bounding section, greater than that on its lower one. There would generally, in such cases, be a much greater effort to overcome the cohesion ($\overline{F}$) of the mass along the lateral vertical planes than in the case previously considered. If the valley of the glacier contract somewhat rapidly, the longitudinal pressure may be enormously increased on a given portion of the glacier by the action of the mass behind it, and this increased action will manifestly depend very much on the facility with which the mass behind slides over its bed.

It may be well to take another numerical example in which the conditions are similar to those of the example given above. Let the glacier be something less than half a mile broad, and its inclination about 3°. Then it appears, from the above expression for F_1, that dislocation would not take place, provided the cohesion of the mass were not less than the weight of a column of ice of about 60 feet long, instead of 200 as in the former example. This supposes the mass to slide freely over its bed, and the longitudinal pressure or tension to be the same behind as before; but if we suppose the mass to adhere to its bed, that adherence will help the tangential action along the lateral vertical planes to support the mass. Consequently the force F_1 called into play might be much less than the weight of a column 60 feet long, and might not be sufficient to overcome the cohesion $\overline{F}$, in which case the motion of the mass would be arrested. This conclusion would be strictly applicable only to our *typical* glacier, but is sufficient to explain how, in the actual case of a glacier, the facility of its sliding may increase its power to overcome the obstacles to its motion by the fracturing of its mass.

I have chosen the simplest cases for the purpose of more easily explaining the manner in which the sliding of a glacier increases the dislocating power of the forces acting upon it. In the more complicated cases, in which C and E are taken into account at considerable depths, we shall obtain greater values of the tearing and crushing forces p_1 and p_2. It is the latter which will be principally increased at greater depths. Still it must not be supposed that the mere increase of weight can explain the apparent difficulty already suggested (art. 60), viz., Why, when the mass has been crushed and then immediately regealed under the existing conditions at any proposed point, it should again be crushed at the same point. This second crushing does not, in fact, take place under the same pressure as that under which the regelation took place. This latter process occurs when the pressure depending on the angular distortion of the element, or on the force F, has

been destroyed by the previous crushing; and then the angular distortion, the force F, and the increase of the maximum pressure are reproduced, and the mass is crushed again. We thus understand how the alternate processes of crushing and regelation must be repeated when the mass is in motion, though the weight alone of the mass, however great, might not, and probably would not, if unaided by the distortion arising from the motion, be sufficient to crush any even the lowest portions of the glacier, any more than the superincumbent weight of a mountain crushes the lower portion of the strata which compose it. We have seen how this power of distortion is increased by the sliding of the glacier.

It is thus that I conceive the process of regelation in glaciers to be intimately united with their uniform sliding movement. Both these properties are proved to belong to ice at the same particular temperature (that of freezing), by clear and conclusive experiments, and form, as I have endeavoured to show, the foundation of a theory which explains all the principal observed phenomena in the motion of glaciers, without assigning to ice any property, like viscosity accurately defined, which it cannot be experimentally proved to possess. In the introduction to this paper I have shown that the property of regelation is totally distinct from that of plasticity or viscosity, if by either of those terms it is intended to designate a determinate property of bodies distinct from that of solidity. All the experimental elucidations which have been given of the Viscous Theory have been drawn from bodies, such as moist plaster of Paris, tar, treacle, unconsolidated lava, &c., all of which may with strict propriety be termed plastic or viscous; but I maintain that ice possesses no property which at all assimilates it to those substances. I have shown that the *apparent* plasticity of ice, as manifested in the compressions of glaciers under great pressure in the course of their motion, is no determinate property of ice at all, but a consequence of its fracture and regelation. Still, differing as I do from the author of the Viscous Theory, I consider the scientific world largely indebted to him for his unwearied researches respecting glacial phenomena, for the large amount of general and detailed knowledge which he has communicated to us, and the interest with which he has helped to invest the subject. Moreover, though he may not have been the first to observe that fundamental character in the motion of a glacier which consists in the more rapid motion of its axial portions, he was the first glacialist whose mind was thoroughly imbued with the necessity of recognizing the influence of molecular mobility in the mass of a glacier on its general onward motion. In like manner, though not absolutely the first to observe that interesting and characteristic structure of glacial ice, the veined structure, he was doubtless the first to recognize the existence of law in that structure, and its consequent importance as indicating the operation of causes physical or mechanical, or both, with which we were entirely unacquainted. In all this, Principal FORBES has contributed largely to the sound progress of glacial science, and his labours must always be highly appreciated. Beyond this boundary, he stepped into the region of speculative theory; and it appears to me, as may be seen from much I have said in this paper, that he did so without any distinct definition of the

fundamental physical principle on which his Viscous Theory rested, and without the experimental verification which it demanded, and, moreover, without the guidance of those more refined and exact mechanical researches without which I am sure we can see our way but dimly through the more complicated of those problems which glacial theory presents to us. Hence it is that I have been led to dissent from most of his speculative views. That dissent has been unreservedly expressed in this paper, and therefore it is that, in concluding it, I would bear testimony to what I consider the great and legitimate claims which the author of the Viscous Theory (however we may differ from the theory itself) has established to be regarded as one of the leading promoters of glacial science.

After the greater part of this paper was written, a very interesting memoir by the Master of the Mint, "On Liquid Diffusion applied to Analysis," was brought under my notice. He there speaks of the "colloidal condition of matter" (of which gelatine seems to afford the type) as opposed to the "crystalloidal condition." He remarks (Philosophical Transactions, Vol. 151, Part I. 1861), "Ice itself presents colloidal properties at or near its melting-point, paradoxical though the statement may appear." Again, "Ice, although exhibiting none of the viscous softness of pitch, has the elasticity and tendency to rend seen in colloids." "It further appears to be of the class of adhesive colloids. The redintegration (regelation of FARADAY) of masses of melting ice when placed in contact, has much of a colloid character. A colloidal view of the plasticity of ice demonstrated in the glacier movements will readily develope itself."

These passages were written without any direct reference to glacial questions; but it occurred to me that a glacialist might possibly put constructions on them unfavourable to the views I have expressed respecting the *solidity* of ice, and the absence in that substance of any property which could, according to my own definition of the term, be called *plastic*. Consequently I wrote to the author requesting him to give me some further elucidation of his views on one or two points bearing on my own definitions and explanations. I proposed to him the following questions, to which he kindly gave me the subjoined clear and explicit replies.

(1) "Is the tendency to a colloidal character in ice, as opposed to a vitreous, crystalline brittle structure, sufficient to interfere materially with the *restitution* described*, by giving the ice a greater degree of plasticity?" Mr. GRAHAM'S answer was, "I believe not. A colloid, on the contrary, is often as nearly perfectly elastic as possible. Take the gluey material used to form the roller by which ink is applied in book-printing, as an illustration of the elasticity of a colloid, with the entire absence (apparently) of true plasticity or viscosity."

(2) "Will the colloidal state of ice at temperature = zero (C.) materially modify the *modus operandi* (assuming the ice to be solid), rendering it approximate to the process which would take place supposing the mass to be plastic?" Mr. GRAHAM replies,

* See art. 1.

"Quite the contrary. The only influence to be looked for from the colloidal state would be greater elasticity—that is, the matter would be likely to yield more before rending or breaking, supposing it to be colloidal, than if it were crystalline. Your mechanical conception of the *modus operandi* in the fracture of a solid (not plastic) applies equally well to a crystal or colloid. I go entirely with you up to that point."

Mr. GRAHAM further remarks, "Colloidality is invoked chiefly with the view of accounting for the ready reunion, the redintegration as I have called it, of fragments of ice brought into contact with each other. It is a very general (perhaps universal) character of colloids to adhere and reunite when two masses are pressed together. In fact all our adhesive substances, gum, glue, starch, &c., belong to the class of colloids. Even glass, which is a colloid of fusion, shows the adhesive character, two sheets of polished plate glass often adhering so thoroughly as to tear up each other's surface when forcibly separated. Another colloid adhesive like ice, is fused phosphoric acid—'glacial' phosphoric acid as it is called, in prescience, one might imagine, of this discussion! No such adhesive property is ever found in crystalline surfaces, so far as I am aware. It is *quà* colloid that ice appears to be adhesive. The discovery of FARADAY'S, of the adhesive quality of ice, is the fundamental fact of the glacier discussion. The name 'regelation' applied to it may, however, be objected to, being quite speculative, and implying, as it appears to do, that two pieces of ice come to be *cemented together* by the freezing of a film of water between them, instead of simply adhering perfectly and uniting as two pieces of plate glass might do. The great fact, however, remains, and the name is but a trivial matter."

I also thought it right to inquire of Mr. GRAHAM the exact meaning he intended to attach to the word "demonstrated" in the last sentence of the above quotation from his memoir. A glacialist might possibly, I thought, if so disposed, interpret it as meaning "proved" or "fully established." In his answer Mr. GRAHAM says, "For 'demonstrated' I should have said 'indicated' as you suggest." He also remarks, "You will, I am certain, do good service in the glacier discussion by the precision you introduce into the terminology of the subject*. I accept without reserve your definitions of plasticity, &c. In the passage you quote from my paper, I had spoken of ice as plastic in a more general sense, as plasticity is understood, I apprehend, by Professor FORBES†. A solid was looked upon as plastic of which the form can be remodelled *anyhow*—by fracture and reunion, as well as in consequence of viscosity."

These views of the Master of the Mint are so explicitly and clearly expressed that they need no comments on my part, beyond the expression of the high gratification I derive from the coincidence of the opinions stated in his letter with those which have been put forth in this memoir.

* I had communicated my definitions to Mr. GRAHAM.

† This is what I termed *quasi-plasticity*, or *apparent plasticity*.

XXXII. *On the Anatomy and Physiology of the Spongiadæ.*—Part II.

By J. S. Bowerbank, *LL.D., F.R.S., F.L.S. &c.*

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Keratode

Is the substance of which the horny elastic fibres of the skeleton of the officinal sponges of commerce are composed. It has, correctly speaking, no relationship either chemically or structurally with horn, and Dr. Grant has judiciously rejected the term "horny fibre" as applied to the sponges of commerce, and has substituted that of keratose by way of distinction; and in accordance with that term I propose to designate the substance generally as keratode, whether it occurs in the elastic fibrous skeleton of true *Spongia*, which are composed almost entirely of this substance, or of those of the Halichondraceous tribe of Spongiadæ, where it is subordinate to the spicula in the construction of the skeleton, and appears more especially in the form of an elastic cementing medium. In a dried state it is often extremely rigid and incompressible, but in its natural condition it is more or less soft, and always flexible and very elastic. It varies in colour from a very light shade to an extremely deep tint of amber, and it is always more or less transparent. In its fully developed condition, in the form of fibre, it appears always to be deposited in concentric layers; but in the mode of the development of these layers there are some interesting variations from the normal course of production. As we find in *Aranea diadema*, the common Garden Spider, that the creature has the power of modifying the deposit of the substance of its web so that the radiating fibres dry rapidly while the concentric ones remain viscid for a considerable period, so we find in the production of the young fibres of the skeletons of the Spongiadæ in some species, as in those of commerce, there is no adherent power at the apex of the young fibre, excepting with parts of its own substance; while in *Dysidea*, and in some other genera, the apex of the newly-produced fibre is remarkably viscid, adhering with great tenacity to any small extraneous granules that it may happen to touch in the course of its extension; but this adhesive character appears to be confined to the earliest stages of its production only, as exhibited at the apices of the newly-produced fibres, the external surface immediately below the apex exhibiting no subsequent adhesive property.

Lehman, in his 'Physiological Chemistry,' Cavendish Society's edition, vol. i. p. 401, states that *Spongia officinalis* of commerce consists of 20 atoms of fibroin, 1 atom of iodine, and 5 atoms of phosphorus; and in treating of the physiological relations of fibroin as regards sponges, he observes, "Its chemical constitution affords one of the arguments why the *Spongia* should be classed among animals and not among plants,

since in the vegetable kingdom we nowhere meet with a substance in the slightest degree resembling fibroin."

From the general physiological characters of the skeletons of the Sertularian and other Zoophytes, I had long suspected that their component parts were identical, or very nearly so, with those of the skeletons of the Spongiadæ, and I therefore applied to my friend Mr. George Bowdler Buckton to assist me in determining this point, and he very kindly undertook to make comparative qualitative analyses of two species of Zoophytes, *Sertularia operculata* and *Flustra foliacea*, with the fibres of *Spongia officinalis* and of raw silk, and I cannot do better than quote entire the report of the results of his examination:—

"I have examined the Zoophytes you sent me, and have compared their deportment under chemical agency, with that shown by white silk and the fibre of ordinary sponge.

"All the specimens were treated in a similar manner, being purified from foreign matter, as far as possible, by boiling for two hours in water, and subsequently for the same period in strong acetic acid. With the exception of *Flustra*, the substances exhibited by this treatment little change in their outward appearance. Carbonate of lime enters so largely into the composition of *Flustra*, that its disintegration by acids ought to cause no surprise.

"From the results of the first seven experiments, which for convenience I have arranged in a Table (see next page), I conclude that all these bodies contain the same, or a very similar animal principle, which I suppose to be identical with Mulder's fibroin. The varying colours of the precipitates from tannic acid and ammonia, I think are probably due to the traces of sesquioxide of iron present in the fibres, and the difference in shade is simply caused by the greater or less preponderance of that metal.

"Although I have not been able to obtain fibroin in a state of chemical purity, I would state that, to my knowledge, there is no vegetable principle which behaves itself towards reagents in a manner similar to that shown by the substance of silk, sponge, &c.

"Mulder and Crookewit's analyses show silk and sponge scarcely to differ in composition.

Fibroin from silk.		Fibroin from sponges.	
Carbon	48·5	Carbon	46·5 to 48·5
Hydrogen	6·5	Hydrogen	6·3 6·3
Nitrogen	17·3	Nitrogen	16·1 16·1
Oxygen, Sulphur, &c. &c.	27·7	Oxygen, Sulphur, Phosphorus, Iodine	31·1 29·1
	100·0		100·0 100·0

"Schlossberger has recently expressed his doubts of the identity of composition of

these bodies, from the circumstance that silk is readily soluble in strong ammonia, saturated with oxide of copper, whilst sponge is scarcely, or not at all, affected by long maceration. My own experiments prove the same fact, yet it is not impossible that the minute quantities of iodine, phosphorus, and sulphur present in sponge may modify the solubility of the fibre.

"Under the supposition that a resinous gum might act as a protection, portions of sponge were boiled in benzol, ether, and alcohol, but these solvents did not modify the characters in any noticeable degree.

	Flustra foliacea.	*Sertularia operculata.*	*Spongia officinalis.*	Silk from *Bombyx.*
Ignited.	Yields a nitrogenous odour. Leaves much ash, in the form of a facsimile of the frond. Chiefly composed of carbonate of lime.	Yields a nitrogenous odour. Leaves much ash, but much less than the preceding.	Yields a nitrogenous odour. Leaves a white ash in some quantity.	Yields a nitrogenous odour. Leaves much ash.
Boiled in water and subsequently in acetic acid.	Acid disengages much carbonic acid. The zoophyte disintegrates and leaves a brown flocculent residue.	Apparently unaffected. Form unchanged.	Apparently unaffected. Form unchanged.	Apparently unaffected. Form unchanged.
Washed and boiled in concentrated hydrochloric acid.	Greater part soluble in the acid. A brown gelatinous mass remains.	Almost entirely dissolved after ten minutes' boiling.	Almost entirely dissolved. The residue is gelatinous.	About ¾ soluble in the acid. Gelatinous residue.
Tannic acid added to the hydrochloric acid solution.	A white precipitate, insoluble in acetic, but soluble in oxalic acid.	A white precipitate.	A white precipitate.	A rather copious white precipitate.
Potash added to the hydrochloric acid solution. Ammonia gives similar reactions.	Precipitation of a few flocks.	No precipitate of any consequence.	Small quantity of a gelatinous precipitate.	A few flocks precipitated.
Tannic acid added to the above neutralized solution.	An abundant yellowish precipitate. If alkali in excess, the precipitate is violet.	Abundant precipitate, which turns reddish purple by excess of alkali.	Abundant precipitate. Coloured by excess of alkali.	Copious precipitate, which takes a flesh tint by excess of ammonia.
Bichloride of mercury added to the hydrochloric solution.	Slight white precipitate.	Slight precipitate.	Slight precipitate.	Precipitate rather more copious than that from sponge.
Boiled in a solution of oxide of copper in ammonia.		Insoluble.	Insoluble.	Perfectly soluble; not again precipitated by acetic acid.

"I consider, however, that this difference between sponge and silk in no wise affects the question of the former substance being a product of the animal kingdom, which the other experiments, I think, satisfactorily prove."

In considering the results of these analyses with a view to proving the animal nature of the Spongiadæ, the evidence afforded by the coincidence of its structural character and its chemical constituents with those of *Sertularia operculata*, is still more conclusive than that derived from the chemical constituents of silk; and, in truth, the action of the chemical agents on the zoophyte and the sponge, as might naturally be expected, are almost in perfect accordance.

Membranous Tissues.

These structures may be divided into two classes.

1st. Simple membranous tissue.

2nd. Compound membranous tissue.

The first is a simple, apparently unorganized, thin pellucid tissue. It is evidently not composed of an extension of keratode, as it is rapidly decomposed after the death of the animal. It is found in abundance filling up the areas of the network of the skeleton in a great variety of sponges, and it appears to be capable of secreting sarcode on both its surfaces when thus situated; on the dermal membranes the sarcode is found on the internal surface only.

Compound Membranous Tissue.—These structures consist of simple membranous tissue combined more or less with primitive fibrous tissue. Their most simple forms exist in the membranes lining the interstitial cavities of the sponge, and in the dermal membranes.

It is difficult in some cases to discriminate between this class of tissues and simple membranes, unless it be by the aid of their functional characters, as the compound tissues are frequently quite as pellucid, although not so thin, as the simple ones.

In dermal membrane, and the membranous linings of the internal cavities of the sponge, they are thin and very translucent; but on careful examination with high microscopic powers and transmitted light, with the aid of polarization, we frequently detect the elastic primary fibrous tissues incorporated with the structure. In the contractile membranes forming the oscular diaphragms in *Grantia*, and in those at the base of the intermarginal cavities in *Geodia* and *Pachymatisma*, they attain a greater degree of thickness, and especially in the two latter genera of sponges. In *Alcyoncellum*, Quoy et Gaimard, the organization of their tissue is still more complex, and we there find them constructed of repeated layers of membranous structure, abounding in primitive fibrous tissue disposed in parallel lines in each layer, the fibres disposed so closely together as to completely cover the membrane beneath, and the direction of the fibres being at various angles to the axis of the great cloacal appendages of the sponge, so as most effectually to aid in the contraction or expansion of that organ. They are so closely packed together and so intermingled, that I could not ascertain their length; but from the gradual

attenuation of some of their terminations, they would seem not to be continuous for any considerable distance. On some of the layers of this compound membrane the fibres were disposed in an even and continuous stratum, while on others they were gathered into broad, flat, parallel fasciculi. When the compound structure consists of several layers of fibro-membranous structure, the disposition of the fibres on the different layers is not coincident. In some cases they cross each other at right angles, while in others the angle does not exceed 45 degrees. The latter mode of arrangement appears to prevail in the membranes connecting the great longitudinal fasciculi of spicula, forming to a great extent the skeleton of the cloacal appendages of the sponge; while the arrangement at right angles appears also in the tissues immediately surrounding the great skeleton fasciculi.

This fibro-membranous tissue abounds in the dermal and interstitial structures of the sponges of commerce, but the greatest development of this structure is exhibited in the genus *Stematumenia*.

Fig. 4, Plate XXVII. represents a small portion of the lining membrane of one of the great excurrent canals of the common honeycomb sponge of commerce, in the condition in which it came from the sea. The primitive fibrous tissue is seen arranged in a single layer in parallel lines at right angles to the long axis of the canal, but partially obscured by the stratum of sarcode on the membrane.

Fig. 3, Plate XXVII. represents a small portion of the dermal membrane of a *Stematumenia*, in which the primitive fibres are seen wandering in every direction over the surface of the membrane.

Figs. 1 & 2 in the same Plate represent portions of a stouter and a more compound membranous structure, from the walls of one of the great cloacal projections from the surface of *Alcyoncellum robusta*, Bowerbank, MS. In this case the membrane is strengthened by two or more layers of primitive fibrous structure, the parallel fibres of each crossing the others at various angles.

Fibrous Structures.

There are two well-characterized classes of fibrous structure.

1st. Primitive fibrous tissue.

2nd. The fibres of the skeleton.

1. *Primitive Fibrous Tissue.*

The first of these tissues is exceedingly minute. The fibres are cylindrical in form, and are usually of considerable length; but where they are fully developed, they occur in such numbers, and in such a matted condition, that I have been unable to separate an unbroken one from the mass. They continue through the whole of their length as nearly as possible of the same diameter, and there rarely appears to be any attenuation towards their terminations, which are usually obtuse. They are evidently very elastic and contractile. When partially separated from their attachments to the membranes, the free ends seldom remain straight, and most frequently they curl considerably in dif-

ferent directions. They appear to be perfectly solid; I could not by the aid of polarization discover the slightest indication of a central cavity. They vary in diameter in different species of sponge, and frequently even in the same individual. In a species of *Stematumenia* from the Mediterranean, I measured an average-sized fibre which was $\frac{1}{4160}$ inch in diameter, while a smaller one, closely adjoining, measured $\frac{1}{9375}$ inch. In this genus these fibres are more fully developed and larger in size than in any other sponges with which I am acquainted. In the sponges of commerce, in the membranes of which they are exceedingly numerous, they are much more slender. In one of the excurrent canals of the common honeycomb sponge, one of the largest measured $\frac{1}{10000}$ inch in diameter, and one of the smallest $\frac{1}{17647}$ inch. In the dermal membrane of the best Turkey sponge they were still less, not exceeding $\frac{1}{18000}$ inch.

This description of fibre is not an absolutely necessary constituent of a sponge, and in many of the Halichondraceous tribes it is exceedingly difficult to find even a single straggling fibre on the interstitial or dermal tissues, while in other genera, as in *Spongia*, *Stematumenia*, and *Alcyoncellum*, they form an important element in the structure of the compound membranous tissues, in which they are closely disposed in parallel lines, occasionally giving off branches, but never appearing to anastomose with each other like the larger fibres of the skeleton.

These fibro-membranous tissues were described by me in the 'Annals and Magazine of Natural History,' vol. xvi. p. 406, plate 14, figs. 1, 3, 4 & 5, in my description of the genus *Stematumenia*.

If a small portion of the dermal membrane of a young Stematumenia be carefully removed from the surface of the sponge, the primitive fibres will be seen projecting from the edges of the membrane in considerable numbers; and occasionally they may be seen to be furnished with a terminal bulb, the greatest diameter of which is about three times that of the fibre. The bulbs are variable in form; sometimes they are largest at the base, or pear-shaped, at other times regularly oval, or nearly globular. By far the greater number of fibres exhibit no bulbs at their terminations; those which have them are always less in diameter than the general average of the fibres. Sometimes, but not very frequently, the bulb exhibits faint traces of a nucleus. On examining the dermal membrane by transmitted light and a linear power of 666, I found numerous globular cells collected in groups on various parts of its inner surface, many of them having a well-defined central nucleus; and among these cells I found the bulbs imbedded with the fibres emanating from them, and in no respect differing in appearance from the non-fibrous cells around them (Plate XXVII. fig. 5, *a*, *a*). On carefully observing a number of these bulbous fibres that had been removed from their positions on the membrane, I found that the part of the fibre nearest to the bulb was frequently flexuous, as if in a tender and immature condition, and in these cases the marginal line of the fibre was continued without the slightest break or interruption into and around the bulb, as represented in Plate XXVII. fig. 6, *a*. At this period of the development the young fibre does not measure above half the diameter of a mature one, and there is no indication of an ultimate separation from the bulb; but when the fibre has attained nearly the

full size the separation is then distinctly indicated; the basal end of the fibre immersed in the bulb becomes hemispherical, and a constriction appears at the junction of the fibre with the exhausted cell. Sometimes, when thus affording indications of their ultimate separation, the cell still retains its rotundity, but all indication of its nucleus has disappeared, and it is perfectly transparent, as represented in Plate XXVII. fig. 6, *b*; while in other cases it is visible only as a collapsed and shrivelled vesicle adherent to the hemispherical termination of the fibre, as represented in Plate XXVII. fig. 6, *c*. I could not find the slightest indication of bulbs amid the matted mass of fibres lying on the inner surface of the membrane, and it was only at the torn edges of the pieces of membrane under examination, or among the groups of cells, that the bulbs in connexion with the fibres were to be discovered.

2. *Keratose Fibrous Tissue.*

General character of the keratose fibres of the horny skeleton.—The essential character of the fibres of the horny skeleton is, that their normal form is always that of a cylinder, while the network of the skeletons of the Halichondroid sponges, which approach nearest in structure to that of spiculated keratose fibre, is always more or less irregular in shape; and in the fully developed state, generally compressed to a very considerable extent; but a careful examination of the youngest portions of the two forms of skeleton-tissue will always render the difference in the two structures apparent. In the spiculated keratose fibre the keratode is always the predominant element, and the spicula the subordinate one; while in the skeletons of the Halichondroid sponges the spicula always predominate, and the keratode is merely the secondary or surrounding medium. In the former structure, in the extension of the terminations of the skeleton, the keratode is the leading element, while in the latter the spicula take the lead.

The fibre is formed of a succession of concentric layers, its increase in diameter being apparently effected at the external surface. Its longitudinal extension appears to be caused by a progressive elongation of their terminations, and new fibres are frequently to be seen pullulating from the sides of the mature ones. In the dried state it is often extremely rigid and incompressible, but in its natural condition, notwithstanding there is frequently an internal axis of extraneous matter or of spicula, it is often remarkably soft and flexible. The spicula, although immersed in the fibre, evidently possess a considerable amount of mobility within the surrounding medium.

The colour of the fibres is always amber-yellow, varying in different species from a very light to a deep yellow brown tint, and it is always semitransparent. In the living state, when the fibres happen to touch each other, whether by their terminations or laterally, they appear at all times to unite.

The keratose skeleton-fibres vary in their organization to a very considerable extent, but the whole of them may be comprised in the following eight typical forms:—

1. Solid simple keratose fibre.
2. Spiculated keratose fibre.

3. Multi-spiculated keratose fibre.
4. Inequi-spiculated keratose fibre.
5. Simple fistulose keratose fibre.
6. Compound fistulose keratose fibre.
7. Regular arenated keratose fibre.
8. Irregular arenated keratose fibre.

1. *Solid Simple Keratose Fibre.*

The typical form of this description of fibre is that which forms the skeleton of the Turkey sponges of commerce, the structure of which I described in a paper read before the Microscopical Society of London, and published in vol. i. p. 42 of its 'Transactions.' The mature fibre is perfectly solid, and no vestige of a central cavity can be observed in any part of it, either when viewed by transmitted light, or in transverse sections of the fibre, by the aid of a Lieberkuhn. Occasionally, but very rarely, I have seen, in young and immature fibres, faint and irregular indications of there having been a very small central cavity in perhaps the earliest period of their development, but in the mature fibre I have never been able to trace such cavities (fig. 7, Plate XXVII.).

This description of fibre is occasionally surrounded by a membranous sheath, on which is imbedded a beautiful system of hollow fibrils or vessels, which sometimes wind round the skeleton-fibre in a spiral direction, at others assume a longitudinal course, giving off short cæcoid branches, or form a complex and irregular network. In an Australian sponge in my possession, the latter mode is the only form in which they occur. In some of these minute fibrils or vessels I observed numerous minute globules, which were rendered moveable by a slight pressure on the glass under which they were exhibited. The mean diameter of these tubes or vessels was $\frac{1}{9346}$ inch. This tissue is of rare occurrence, and I have been unable to determine whether it is a specific character, or whether it is due to a peculiar condition of the sponge. Fig. 9, Plate XXVIII. represents a portion of fibre from the skeleton of one of the sponges of commerce. Fig. 10, Plate XXVIII. is from a rigid species of Australian sponge. This singular tissue is described more fully in a paper which I read before the Microscopical Society of London in 1841, and which is published in their 'Transactions,' vol. i. p. 32, plate 3.

2. *Spiculated Keratose Fibre.*

This structure is essentially a solid form of keratose fibre, no central cavity ever being visible in its axis. The normal form of the fibre is cylindrical, but it is occasionally more or less compressed, and always contains a thin central line or axis of spicula arranged in longitudinal series. The spicula are secreted within the fibre, and are nearly uniform in size, and always of the same shape in the same species of sponge. In the production of the young fibres, the projection of the new keratode and the secretion of the new spicula appear to be simultaneous. In this class of structure the keratose fibre is

the predominant element, and the spicula the subordinate one, and we accordingly frequently find the fibres destitute of spicula for short distances; but these occurrences are the exceptions, and not the rule of the structure. Fig. 8, Plate XXVII. represents a portion of a longitudinal section of the skeleton of *Halichondria oculata*, Johnston.

The mode of the progressive development of this form of fibre is interesting. In a young specimen of *Halichondria Montagui*, Johnston, I observed that when a new fibre was projected from the skeleton it usually contained a single spiculum, thinly covered by keratode at the apex, and more thickly so towards the basal end. Another spiculum followed the first, the terminations of each overlapping the other; and at the junction of the two, the keratode was accumulated in the form of a plumber's joint, as represented in Plate XXVII. fig. 9, so as to give additional strength to the junction of the spicula, while the middle portion of the second spiculum remained very thinly covered by keratode. When the distal end of the new fibre has attained its proper length, or has become cemented to the side of another fibre, the remaining portion of the keratode is produced, and the fibre then assumes a regular cylindrical form.

3. *Multi-spiculated Keratose Fibre.*

This description of fibre is literally a cylindrical mass of spicula cemented together by keratode, and surrounded by a thin case of the same substance. The spicula are exceedingly numerous, and very closely packed in parallel lines in accordance with the axis of the fibre. They are nearly uniform in size, and always of the same shape in the same species of sponge. In this structure the spicula are the predominant element, and the keratode the subordinate one. Fig. 10, Plate XXVII. represents a fibre from the skeleton of *Halichondria ægagropila*, Johnston.

4. *Inequi-spiculated Keratose Fibre.*

This form of fibre is composed of an infinite number of spicula disposed in every possible direction, cemented together by keratode, and surrounded by a sheath of the same material. The spicula agree in form in all parts of the sponge, and are nearly of the same size. In these fibres the spicula are the predominant element, the keratode the secondary one. In the only sponge in which this form of structure has yet been found, *Raphyrus Griffithsii*, Bowerbank, MS., the fibre is very unequal in size and much varied in its form, frequently becoming very much flattened and expanded. Fig. 11, Plate A. represents a longitudinal section of a small portion of a fibre from the skeleton, showing the irregular disposition of the spicula within it.

5. *Simple Fistulose Keratose Fibre.*

This form of fibre is usually very much larger and more rigid than the solid keratose fibre. It is cylindrical, and continuously fistular. The great central cavity of the fibre usually occupies about one-third of its diameter. It is nearly uniform in its size, but

occasionally it is dilated considerably for a short space, and then resumes its original diameter. In the young state the cavity is as large, or nearly so, as in the adult fibres, while the enveloping keratode assumes the form of a thin transparent amber-coloured coat, which in the mature state becomes frequently twice or three times the thickness of the diameter of the central cavity.

This great fistular space is lined with a thin pellucid membrane, which, in specimens that have been dried, appears to have been thickly covered with minute semi-opake granules. At the time of my first description of this form of fibre, published in the 'Annals and Magazine of Natural History,' vol. xvi. p. 403, I believed that in the natural condition of the fibres the central cavity was an open tube; but subsequent observations on specimens which have never been dried, have led me to the conclusion that the whole of the central space is filled with a minutely granulated substance which presents all the characteristics of sarcode.

There is no communication between the great central fistular canal and the interstitial cavities of the sponge, the projecting ends of the fibres of the skeleton being always hermetically sealed. Fig. 12, Plate XXVII. represents a fibre from the specimen of *Spongia fistularis*, Lamarck, in the Museum at Edinburgh, given to me by Professor Grant.

6. *Compound Fistulose Keratose Fibre.*

In its external characters this description of fibre is not, under ordinary circumstances, to be distinguished from simple fistulose fibre, and it is only when submitted to a microscopic power of about 100 linear that its peculiar character can be detected. We then find that the fibre is not only furnished with a large continuous central cavity, but that it also has numerous minute cæcoid canals radiating from the central one at irregular distances, at nearly right angles to its axis. These secondary canals are very unequal in length, and very few of them reach to near the external surface of the fibre, and none of them appear to perforate it. Their direction is usually in a straight line from the parent canal; a few assume a tortuous direction, and a still fewer number bifurcate or branch. Within the central tubes of the fibres there are frequently one or two minute simple tubular fibres; when more than one they do not unite, but they divide and traverse each a separate cavity, when they happen to reach one of the anastomosing points of the great skeleton-fibre. The structures are described more at length in the 'Annals and Magazine of Natural History,' vol. xvi. p. 405, under the head of "*Auliskia*," a new genus of sponges, founded principally on the compound fistulose structure of its skeleton-fibres. Fig. 13, Plate XXVII. represents a portion of compound fistulose keratose fibre as seen with a linear power of 100. Fig. 14, a portion of a similar fibre under a power of 300 linear.

7. *Regular Arenated Keratose Fibre.*

This description of fibre under ordinary circumstances has very much the appearance of simple fistulose fibre, but when examined by transmitted light with a linear power of

about 100, we find in the centre of the fibre a series of grains of extraneous matter, occupying the place of the large continuous canals of the fistular forms of fibre. The series of extraneous matters is not always continuous, and when an interruption takes place the fibre becomes solid, or faint traces only of a central cavity remain. The mode of the inclusion appears to be due to the extreme terminations of the young fibres being viscid, and thus seizing on any extraneous particles that happen to come in contact with them. The growing keratode quickly envelopes them, and proceeding on its course of extension, seizes in like manner on other particles of sand or solid matter, and thus a continuous and regular chain of extraneous material is imbedded in the axis of the fibre, as represented by figs. 1 & 2, Plate XXVIII. This description of fibre is found in a great variety of keratose sponges, and especially among the coarse rigid skeletons of the Australian species, as represented by fig. 1, Plate XXVIII.; and among the flexible sponges, as represented by fig. 2, Plate XXVIII.

8. *Irregular Arenated Keratose Fibre.*

I have described this form of fibre in a paper descriptive of two species of *Dysidea*, read at the Microscopical Society of London, Nov. 24, 1841, and subsequently published in vol. i. p. 63 of their 'Transactions.'

The adult and fully produced fibre is frequently half a line or more in diameter. It is built up in all parts of its substance of grains of extraneous matter, each one being separately enveloped in keratode. The adhesive power in the young progressing fibre not being confined to its apex only, its sides also seize upon the surrounding grains of solid matter, and the keratode speedily passing round and enveloping them, the whole fibre becomes a solid cylinder of irregularly imbedded molecules. There is a great variety of substances imbedded in these fibres, dependent, as a matter of course, on the amount of material surrounding them at the period of their development. The skeleton of *Dysidea fragilis*, Johnston, a British species very common on the south coast of England, presents one of the best types of this form of fibre. And single grains of sand are frequently to be found among the fibres of the surface of the sponge, elevated on short pedicels of the rapidly growing young fibres, sometimes entirely, and at others only partially enveloped by the progressing keratode. Figs. 3, 4, & 5, Plate XXVIII., represent portions of fibre from the same individual.

This genus of sponges appear, to the best of my knowledge, to be the only animals that construct an internal skeleton almost entirely of extraneous materials.

Siliceous Fibre.

This structure is widely different from any of the keratose fibres which contain either secreted silex in the state of spicula, or extraneous silex in the form of sand. The whole substance of the skeleton fibre consists of solid silex, secreted and deposited in concentric layers, exactly after the manner of the secretion of pure keratode in the fibres of the sponges of commerce. When cleansed from the sarcodous matter by which

they are surrounded in a living state, the fibrous skeleton bears a striking resemblance to fibres of spun glass, and is quite as pellucid and colourless as the artificial material, and the dead sponge quite as brittle. The fibrous skeleton of *Dactylocalyx pumicea*, STUTCHBURY, in its mode of arrangement strikingly resembles that of one of the sponges of commerce; it is equally complex and irregular in its structure, and the component fibres quite as much anastomosed. In that species the fibres are smooth and cylindrical, but in others they frequently abound with minute, obtuse, wart-like elevations.

There is every indication in the skeletons that the increase in diameter, and the extension in length in the fibres are effected in the same manner as in the solid keratose fibres. The free terminations of the young fibres have the same attenuated but obtuse form, and the pullulation of the young fibres from the sides of the mature ones is quite as apparent as in their keratose congeners; but, in the young state, they never appear to be viscid, as the keratose ones frequently are; and extraneous matters are never detected at their apices, or on their substance.

There are two distinct forms of this class of fibre:—

1st. Solid siliceous fibre.

2nd. Simple fistulose siliceous fibre.

The structure of solid siliceous fibre is very similar to that of solid keratose fibre. Occasionally there are indications of a former existence of a minute central canal, but in the fully developed fibre this is rarely visible. The external characters of these fibres vary in each species. In a new siliceous sponge in the British Museum, designated by Dr. GRAY *M'Andrewsia azoïca*, the fibres are quite smooth, as represented in Plate XXVIII. fig. 6. But in the greater number of species they are more or less tuberculated, as in Plate XXVIII. fig. 7, which represents a group of fibres from the type-specimen of *Dactylocalyx pumicea*, STUTCHBURY, a portion of which is in the possession of Dr. J. E. GRAY. In other species in my possession the tuberculation is very strongly produced, as represented in a few fibres of *Dactylocalyx Prattii*, BOWERBANK, MS., Plate XXVIII. fig. 8.

Of the 2nd form, simple fistulose siliceous fibre, I know but one example, and that is the remains of the siliceo-fibrous sponge on which the beautiful specimen of *Euplectella cucumer*, OWEN, is based.

The tubulation of the skeleton-fibre is very similar to that of some varieties of simple fistulose keratose fibre, but the central cavities are not so invariably continuous as in the keratose varieties of fistulose skeleton-fibre. Fig. 11, Plate XXVIII. represents a small piece of the spinulated simple fistulose fibres of the skeleton of Dr. ARTHUR FARRE'S specimen. The spinulation of these fibres is a remarkable character. It is the only case of the production of acute spines on the skeleton-fibre of a siliceo-fibrous sponge with which I am acquainted.

Prehensile Fibre.

In the course of my examination of the fibrous skeleton-tissues, I have found but one instance in which they have developed prehensile organs to assist in the attachment of the sponge, and this is in a minute siliceo-fibrous species, parasitical on the base of a specimen of *Oculina rosea*, from the South Sea. In this sponge the basal fibres curve downward in the form of numerous small, nearly semicircular reversed arches, from the lowest portions of each of which there is a short stout portion of fibre projected; and at about the length of its own diameter downwards, a ring of stout prominent bosses, six or eight in number, is produced, very considerably increasing its diameter at that part, immediately beneath which the fibre is attenuated to a point. These singular organs are admirably calculated to penetrate the porous cavities or fleshy envelopes of the coral, and thus to securely attach the sponge to its adopted matrix (Plate XXVIII. fig. 12).

Cellular Tissue.

The cellular structures in the Spongiadæ are few and very simple in form. We find no series of conjoined cells in the body of the sponge, as in vegetable tissues. The only forms in which true cellular structures occur in the bodies of sponges, are those of detached spherical molecular cells, and of discoid or lenticular nucleated cells. Cellular structures of the first form are found in abundance on the fibres of many species of the true sponges, and are believed by Dr. JOHNSTON to be the reproductive organs of that genus. They are very minute; an average-sized one measured $\frac{1}{11000}$ inch in diameter. They are pellucid, and afford no indications of a nucleus, either single or multigranulate.

Imbedded in the sarcodous stratum on the interstitial membranes in many of the Halichondroid tribes of sponges, we frequently find numerous compressed circular cells. In the greater number of cases they are so translucent as to readily escape observation, even with a tolerably high power; but in other species, as in *Ecionemia acervus*, BOWERBANK, MS., a new genus of sponges from the South Seas, in the collection of the Royal College of Surgeons, and in *Halichondria nigricans*, BOWERBANK, MS., a British species, these tissues are developed in a more than usually distinct condition.

In the first-named sponge they are thickly dispersed on the surfaces of the interstitial membranes, but without any approach to order or arrangement. They are decidedly lenticular in form, with a well-defined transparent nucleus, which varied in size from about one-fourth to three-fourths the diameter of the cell in which it was contained. The cells varied considerably in size; the largest I could find was $\frac{1}{3500}$ inch in diameter, and one of the smallest $\frac{1}{10000}$ inch, but the greater number were about $\frac{1}{7000}$ inch in diameter (Pl. XXVIII. fig. 13). In *Halichondria nigricans* they do not appear to be quite so convex as in *Ecionemia acervus*, nor are they so numerous as in that species, but they are somewhat larger in size; one of the largest measured $\frac{1}{3500}$ inch in diameter, and a small one $\frac{1}{5000}$ inch; they are represented *in situ* in Plate XXVIII. fig. 14.

The only instance with which I am acquainted of a conjoined arrangement of such

cells exists in the envelope of the ovaries * of *Spongilla Carteri*, the species described by CARTER in his "Account of the Freshwater Sponges in the Island of Bombay," which that author believed to be *Spongilla friabilis*, LAMARCK, but which proves to be a distinct species, which I have named after its discoverer, as a slight recognition of the good services he has rendered to science by his excellent and accurate observations. These cells may be detected *in situ* after the envelope of the ovary has been submitted for a very short time to the action of hot nitric acid, so as to render the coriaceous envelope semitransparent without destroying it. The structure of its walls is then seen to consist of linear series of cells, closely packed together in lines of six or eight in each, radiating from the centre of the ovary to its external surface. They do not appear to be absolutely in contact with each other, but are usually seen to be separated by a thin stratum of a transparent substance, probably an indurated membrane or sarcode. At the surface of the envelope they frequently appear to be somewhat hexagonal from mutual compression. I could not detect a nucleus in any of them (Plate XXVIII. fig. 16). CARTER and other writers on *Spongilla* have designated the granulated forms of the sarcode in those sponges, "Sponge cells," but I cannot coincide with that opinion. I have frequently tried in vain to detect a proper coat of cellular tissue on the Amœba-like granular masses into which *Spongilla fluviatilis* resolves itself at certain periods of its existence, and neither in a healthy and active condition, nor in a state of partial decomposition, have I ever been able to satisfy myself of the existence of a surrounding membrane. It appears to me that these bodies are the result of a natural resolution of the sarcode into granular masses of various sizes, each of which, on being liberated from the parent body, becomes an independent gemmule, which is capable of reproducing the species of sponge from which it emanates. And I have long suspected that the Amœbæ found in ponds and rivers, and also in sea-water, are not in reality distinct species of animals, but that they are free portions of the sarcode of various species of Spongiadæ.

Sarcode (*Physical Character*)

is a pellucid, semitransparent gelatinoid substance, variable in colour and insoluble in water. It dries readily, and its physical characters are restored by immersion in water with little or no apparent alteration. It is usually spread thinly and rather evenly over the internal tissues, but the surface is rarely perfectly smooth; sometimes it abounds in obtuse elevations, and occasionally separates naturally into innumerable irregularly round or oval masses which are exceedingly variable in size. When examined by transmitted light with a microscopic power of 400 or 500 linear, it is always found to contain innumerable minute molecules of apparently extraneous animal or vegetable matter, the molecules being always more or less in a shrivelled or collapsed condition, and very variable in size. Occasionally it is found abundantly furnished with lenticular nucleated cells, nearly uniform in size, and often highly coloured. Fig. 1, Plate XXIX. represents a portion of

* These bodies have hitherto been termed Gemmules. For their characters as ovaries I must beg to refer the reader to the section of this paper on Reproduction.

the interstitial membrane of the honeycomb sponge of commerce, with the sarcode in its natural condition, filled with the remains of the nutrient molecules in a collapsed state. Figs. 13 & 14, Plate XXVIII., exhibit the same tissues with the addition of nucleated cells immersed in the sarcode. In the sponges of commerce it is exceedingly largely developed, and nothing can be more different in character than their soft and flexible skeletons and the animal in its natural condition. Specimens of it in this state, which have been preserved in spirit immediately on being taken from the sea, have the whole of their interior nearly as solid and firm as a piece of animal liver, the colour being a very light grey or nearly white. While the sponge, as a whole, is sensitive and amenable to disturbing causes, the sarcode does not appear to be especially so, as I have frequently observed a minute parasitic annelid which infests the interior of *Spongilla fluviatilis*, passing rapidly over the sarcodous surfaces, and biting pieces out of its substance without apparently creating the slightest sensation to the sarcode, or at all interfering with the general action of the internal organs of the sponge; and in many cases we find foraminiferous and other minute creatures permanently located in its large cavities without appearing to cause it the slightest inconvenience.

When separated from the living sponge, it has at certain periods an inherent power of locomotion; small detached masses of it may be observed slowly but continuously changing their form, and occasionally progressing in different directions; and Carter, in his valuable 'History of the Freshwater Sponges of Bombay,' describes such detached masses of sarcode, when progressing and encountering a fixed point, as dividing longitudinally to avoid the impediment, and again uniting when it has been passed. This gliding motion appears to be dependent on an inherent contractile power, as no cilia have been detected on the surface of such locomotive masses. Dujardin has recorded similar movements in portions of the sarcodous substance from specimens of his genus *Halisarca*; and similar observations have been recorded by Lieberkuhn and other writers during their observations of the Spongiadæ. I have frequently, at different seasons of the year, taken portions of the sarcode from living and healthy specimens of *Spongilla*, in which I could not by the closest observation detect these motions, which are so readily to be seen at other periods of their existence; and even at the same period of the year the sarcode of some specimens exhibits these motions, while in others they could not be detected. I have often sought for these phenomena in portions of the sarcode of *Halichondria panicea*, *Hymeniacidon caruncula*, and other marine species, but I have never yet been fortunate enough to detect them. It is highly probable that the capability of such motions exists in the sarcode of these and other marine species for a limited period, but it does not appear that such powers of motion are a constant condition of this substance.

ORGANIZATION AND PHYSIOLOGY.

Previously to entering on the subject of the organization and physiology of the Spongiadæ in detail, it will be necessary to take a brief view of the general structure of these animals. Whatever may be their form, or however they may differ from each other in appearance, there are certain points in their organization in which they all agree. In the first place, however variable in its form and mode of structure, there is always a skeleton present, on which the rest of the organic parts are based and maintained. Amidst the skeleton, and intimately incorporated with it, are the interstitial canals, consisting usually of two series; the first appropriated to the incurrent streams of the surrounding water, and the second to the excurrent streams, which they conduct from the interior of the sponge to the oscula at its surface, through which they are discharged. In the event of the absence of the excurrent system of canals, their office is served by the great cloacal cavities that are found to exist in some forms of sponges, extending from the base to the most distant parts of the animal. Beside these large cavities, there are others of a much more limited character, the intermarginal cavities, which are situated immediately below the dermal membrane, and which receive the water inhaled by the sponge and transmit it to the mouths of the incurrent canals which have their origin in the intermarginal cavities. Enveloping the entire mass of the sponge we find the dermal membrane, in which are situated the pores, for inhalation and imbibition of nutriment, and the supply of the incurrent canals; and the oscula, through which the excrementitious matter and the exhausted streams of water are poured from the terminations of the excurrent canals. These parts are indispensably necessary, and are always present in a living sponge. The attachment of the Spongiadæ to the body to which they adhere during life, is effected by a basal membrane which presents a simple adhesive surface, following the sinuosities of the body on which it is based, entering into holes or cracks and filling them up, thus securing a firm hold of the mass on which they are fixed. When it so happens that the locality consists of sand or mud, their bases frequently assume the form of branching roots, which penetrate the mud or sand to a considerable extent; but they are never instrumental to the nutrition of the animal—they are simply the anchors by which it is fixed to its locality for life.

The Skeleton.

There are two important distinctive characters for consideration in treating of the structure of the skeleton:—1st, the material of which it is constructed; and 2nd, the mode of its arrangement.

By selecting the material substance of the skeleton as the means of dividing the Spongiadæ into Orders, we obtain three well-defined natural groups, which are again readily divisible into Families, based on the mode of the arrangement of the substance of which the skeleton is composed.

The first Order, the Keratosæ, consists of those sponges in which the primary essential material of the skeleton is keratose fibre. It may be divided into three families.

1. Those which have the skeletons constructed of keratose fibre only, as in the best cup-shaped Turkey sponges of commerce.

2. Those having skeletons of arenated keratose fibre, as in the genus *Dysidea*.

3. Those which have the skeleton formed of spiculated keratose fibre, as in *Halichondria oculata*, Johnston, *Chalina*, Grant, and in the common West Indian sponges of commerce.

In the first Order no earthy material of any kind enters into the structure of the skeleton.

The sponges of the second Order, by a natural transition, pass into the nearly allied great division of the Halichondroid skeletons; the inability of the former to secrete silex in an organized form connecting them closely with the pure keratose, while the instinctive habit of appropriating extraneous matters recognizes the necessity of other material in the skeleton beside pure keratode; and the secretion of it by its own inherent power appears to be the next natural step in the development of the animals.

In the third division, those having the skeleton formed of spiculated keratose fibre, the gradual development is also well marked, as in one group we find spicula only in the primary or radiating fibres of the skeleton, while in another group they are found in both the primary and secondary fibres, and are developed simultaneously with the keratode of the young fibres of the skeleton.

The second Order, the Siliceæ, comprises those sponges in which the primary essential material of the skeleton consists of siliceous matter; and this also may be divided into three sections or families.

1. Those sponges which have the skeleton composed of solid siliceous fibres, as in *Dactylocalyx pumicea*, Stutchbury.

2. Those in which the skeleton consists of spicula dispersed without order on membranous surfaces, as in *Hymeniacidon caruncula*, Bowerbank.

3. Sponges having the skeleton consisting of spicula cemented together into a network by keratode, as in *Halichondria panicea*, Johnston.

The third Order, the Calcareæ, has the primary essential material composed of calcareous matter, and this division contains but one section or family:—

Spicula dispersed without order on membranous surfaces, as in the genus *Grantia* as defined by Johnston.

1. Keratosæ	. . .	*a.* Keratose fibre only.
		b. Arenated keratose fibre.
		c. Spiculated keratose fibre.
2. Siliceæ	. . . . .	*a.* Solid siliceous fibre.
		b. Spicula dispersed on membranes.
		c. Spicula cemented together by keratode.
3. Calcareæ	. . .	*a.* Spicula dispersed on membranes.

Spicula of the Skeleton.

The spicula in the skeletons of the Spongiadæ appear to be the homologues of the

earthy deposits in the bony structures of the more perfectly developed living forms. In the higher tribes of animals we find the disintegrated condition of the earthy deposits in the first stages of the development of the bony structures in the form of minute radiating patches, which in a more advanced stage unite and form the solid mass of bone, as in the mammalian tribes of animals, while in the cartilaginous tribe of fishes these radiating centres of bony secretion never attain a higher degree of development, but remain isolated points of bony structure during the whole of the life of the animal. And in the compound tunicated animals we find the calcareous stellate and sphero-granulate forms of spicula developed in close accordance with the similar siliceous forms in various species of sponges. Thus the stellate and cylindro-stellate spicula of the sarcode in the Spongiadæ are *apparently* the homologues of the bony centres of development in the higher animals. It is so likewise with the other forms of sponge spicula. We find isolated calcareous spicula of an irregular fusiformi-acerate shape, representing the bony skeleton of the higher animals in the outer integuments of several species of *Doris*.

Messrs. Alder and Hancock, in their admirable 'History of the British Nudibranchiate Mollusca,' describe calcareous spicula occurring in *Doris aspera*, *bilamellata*, and *Triopa claviger*, which *appear* to be analogous to the rectangulated-triradiate spicula of *Grantia*; and they also state that in the first-named species crucial or dagger-shaped spicula occur in the branchiæ and margins of the cloak of the animal, and forms very similar to those occur on the interstitial membranes of *Grantia nivea*, Johnston. Numerous forms of tuberculated and smooth calcareous spicula are also found in the extensive family of the Gorgoniadæ. And the siliceous simple bihamate form of retentive spiculum, so abundant on the interstitial membranes of many species of sponges, are closely represented by the calcareous bihamate spicula so numerous on the tubular suckers of *Echinus sphæra*. Thus we find in the spicula only, a series of links in the chain of animal development, intimately connecting the Spongiadæ with the higher tribes of animals.

In the solid siliceous fibres of *Dactylocalyx*, and in the tubular siliceous fibres of *Farrea*, Bowerbank, MS., and especially in the latter, we obtain a very much closer approximation to the tubular forms of the bones of the higher classes of animals.

From our knowledge of the great scheme of the natural development of animal life, the most perfectly organized sponges appear to be those which secrete carbonate of lime as the earthy basis of their skeletons, and the least perfect those which secrete no earthy matter in the skeleton; those which secrete silex taking an intermediate position; but it must also be remembered that there is no form of spiculum found among the calcareous sponges, or in the higher tribes of animal life, that is not repeated among the siliceous forms of spicula of the Spongiadæ.

The essential Skeleton Spicula.

The general configuration of the spicula, which are essentially necessary to the structure of the reticulated skeletons, is that of simple elongate and slightly curved bodies, varying in length and stoutness in accordance with the necessities of the structure in

which they form so important an element. When the areæ of the reticulations are large, they are generally long and rather stout, and are usually shorter when the proportions of the network are small and close. When enclosed in keratose fibre, they are most frequently smaller and shorter in their proportions than those in the Halichondroid sponges. And in those species in which they are dispersed over the membranous tissues, as in *Hymeniacidon*, Bowerbank, MS., they are generally long, slender, and frequently flexuous. In the sponges of this structure having siliceous spicula the triradiate form of spiculum occurs but rarely, while in the calcareous sponges, which consist of membranes and dispersed spicula, the triradiate forms of skeleton spicula are the normal ones.

When the skeleton is constructed of large fasciculi of spicula, as in *Tethea* and *Geodia*, they attain their greatest dimensions as essential spicula of the skeleton, frequently exceeding the eighth of an inch in length.

The greatest known length of spicula occurs in the prehensile ones of *Euplectella aspergillum* and *cucumer*, Owen, where they are found to exceed three inches in length; and in *Hyalonema mirabilis*, Gray, where, in the spiral column of the great cloacal appendage, they reach the extreme dimensions of six or seven inches in length; but in both these cases the spicula must be considered as auxiliary and not essential forms.

The larger number of forms of skeleton spicula are perfectly smooth, but in some species they are partially or entirely covered with spines.

In every case they appear in the living state to have the capability of a change of position within the fibre to a considerable extent, in accordance with the natural alterations arising from the extensions or contractions of those tissues.

The spicula are among the earliest-developed organs of the sponge. Dr. Grant, in his valuable "Observations on the Structure and Functions of the Sponge," published in the Edinburgh New Philosophical Journal, vol. i. p. 154, states that spicula are developed in the locomotive gemmules of *Halichondria panicea* (*Hal. incrustans*, Johnston) before they attach themselves for life and commence their development as fixed sponges. And in the gemmules of *Tethea cranium* they are abundantly developed even before the gemmules are detached from the parent, and some of them are of forms peculiar to the gemmule.

The growth of the spicula and their mode of extension appear to vary according to circumstances. Thus an acerate spiculum is at first short and very slender; as the development proceeds it increases in diameter, and appears to lengthen equally from the middle towards both ends; but in spinulate ones the increase in length does not appear to be effected in the same manner as in the acerate form, as we often find spinulate spicula fully developed at the base, while the shaft is exceedingly short and the apical termination hemispherical instead of acutely pointed, as in the adult state. As the shaft lengthens towards its full proportions, it attenuates; but in all the intervening stages the apical termination is usually more or less hemispherical. The progressive development from the base to the apex of the spinulate form is beautifully illustrated in the skeleton spicula of a new and very singular British sponge from Shetland, *Halicnemia patera*,

Bowerbank, MS., represented by figs. 2, 3, 4, 5, 6, & 7, Plate XXIX. The first of these (fig. 2) represents a short variety of the normal spinulate form. In the second (fig. 3) we have a bi-spinulate, and in the third (fig. 4) a tri-spinulate form. The latter two are not mere malformations, but they prevail to a great extent in the structures of the sponge, subject to variations in the distances in the development of the second and third inflations from the basal one. Figs. 5, 6, & 7 represent immature spicula in progressive stages of development, the apices having hemispherical terminations.

Auxiliary Spicula.

Beside the spicula essential to the structure of the skeleton there are several other forms of these organs, many of which, although not absolutely necessary in the structure of the skeleton, are of very frequent occurrence in subsidiary organs found in particular species and in peculiar genera. They may be conveniently classed under the following heads:—

Connecting spicula.
Prehensile spicula.
Defensive spicula.
Tension spicula.
Retentive spicula.
Spicula of the sarcode.
Spicula of the gemmules.

In the above designations of the auxiliary spicula, it must not be understood that their respective titles strictly define their offices, as it frequently occurs that under peculiar circumstances the same form of spiculum is destined to serve two, or even three distinct purposes. Thus, an external defensive spiculum will occasionally perform retentive offices for the purpose of securing prey; or internal defensive spicula will combine the offices of defensive spicula against the larger and more powerful of their enemies with that of wounding and securing their smaller ones.

The Connecting Spicula.

The normal form of the connecting spicula is that of an elongate shaft, with a ternate apical termination. But all the varieties of this form are not necessarily connecting spicula. Some of them subserve the offices of external or internal defensive organs, as I have described elsewhere. The varieties that may correctly be designated by this title are those which I have termed in the first part of this paper expando- and patento-ternate spicula, and some varieties of the recurvo-ternate form also appear to be applied to this peculiar office. Their situation in the sponge, rather than their precise form, determines their title to be thus designated. Nor is their especial purpose of connecting the dermal crust of the sponge with the great mass of the skeleton beneath, the only office they are destined to perform in the economy of the animal, as their ternate terminations are so disposed as to form a series of reticulations and areas for the support of the valvular membranes of the proximal ends of the intermarginal cavities of the sponges, in which

they are best developed, as in *Geodia M'Andrewii* and *Barretti*, *Pachymatisma Johnstonia*, and others of similar structure.

I have never seen the progressive development from a simple elongate shaft of an expando- or patento-ternate connecting spiculum, as I have those of the porrecto-ternate external defensive form, and the spinulo-recurvo-quaternate internal defensive ones, but from the great similarity that exists in their structure there can be little doubt that their mode of growth is the same; and I am very much inclined to believe that the cylindro-expando-ternate form from *Pachymatisma Johnstonia*, fig. 43 in Plate XXIII. of the Phil. Trans. for 1858, is an incompletely developed form of the mature attenuato-expando-ternate spiculum that belongs to that sponge, and which is represented by fig. 42 in the same Plate.

There is a progression of development in the ternate terminations of these spicula that is very interesting. The simplest form has three nearly straight attenuating radii. In the next stage the distal ends of the primary radii become furcated, but the secondary radii remain in the same plane as the primary ones. In the third stage of development the terminations of the secondary radii again divide into furcations, becoming dichotomo-patento-ternate (fig. 48); but in this case the radii of the extreme furcations are not all in the same plane, as appears always to be the case with those of the secondary radii, and thus we have produced an additional power for combined action. But in the whole of these varieties, in the structure of these ternate terminations, hitherto, there is no appearance, further than their general form, of their being destined to become a united structure, and in some sponges in which they do occur they rarely, or never, become thus united; but this demonstration of their destination for combined action is obtained in an irregular ternate form, as exhibited in the dermal structures of a new species of siliceo-fibrous sponge from India, *Dactylocalyx Prattii*, Bowerbank, MS., in which we have the primary radii sinuated and flattened in such a manner as to splice together and form a strong and regular reticulated structure for the support of the dermal membrane of the sponge, as in fig. 8, Plate XXIX., which represents a few of these spicula uniting to form the reticulations of the dermal tissues, while fig. 9 represents three of these spicula separated by boiling nitric acid. By this structure, as exhibited in *D. Prattii*, there is rendered apparent a more visible and common purpose in their form and mode of development, and we are gradually conducted to the still more complete and continuous form of fibro-siliceous dermal network that exists in the beautiful harrow-shaped tissue of the dermal structures of the sponge supporting the fine specimen of *Euplectella* in the possession of my friend Dr. A. Farre, and described by Prof. Owen in the 'Transactions of the Linnean Society,' vol. xxii. p. 117, plate 21, and which tissue I shall describe more fully in treating on the subject of the dermal structures of the Spongiadæ.

There are two distinct purposes in the physiological application of the ternate spicula; the simplest is that of the strengthening and connecting the dermal membrane with the mass of the animal beneath. The second and more complex one, is that of forming an internal reticulating framework for the support within its areas of the valvular tissues

forming the bases of the intermarginal cavities. These offices of the ternate spicula are not demonstrated in an equal degree of perfection in all sponges in which they occur. Where the organs which they subserve are best and most abundantly developed, these forms of spicula are found in the greatest quantities, and in the most regular and perfect mode of arrangement, but where the intermarginal cavities or porous areas are in a less regularly developed state, they are deficient in a corresponding degree; thus evincing the design and purpose of their structure and presence. The most perfect and beautiful illustration of their physiological purpose, in their first mode of application, is afforded by the dermal membrane of *Dactylocalyx Prattii*. Here we find their radii overlapping each other longitudinally, and cemented together by keratode, forming a continuous and regular network, upon the upper surface of which the dermal membrane reposes, and to which it is firmly united. The mode in which the radii are united, and the material with which they are cemented together indicate a unity of firmness and elasticity in the living state that is truly admirable; and this mode of structure we perceive is especially necessary to the action of the dermal membrane, as the whole of the skeleton beneath is perfectly rigid and inelastic. Thus while their shafts are deeply plunged in, and firmly secured to, the immoveable mass beneath, their ternate apices are capable of such an amount of oscillating motion as would be required for the organic expansion and contraction of the membranous structure they support. By the action thus generated each pair of the united radii would glide in a longitudinal direction upon each other, and thus, although in each separate instance the amount of motion would appear to be exceedingly small, the aggregate of the whole would afford a very considerable range of expansion, as exhibited in fig. 8, Plate XXIX.

In their second mode of application, that is to the bases of the intermarginal cavities, it appears that as their office is different, so their form and the mode in which the radii of their apices is connected are also different. Thus at the inner surfaces of the thick dermal crust of *Geodia M'Andrewii* and *Barretti*, we find them forming a network equally regular and continuous as that in *Dactylocalyx Prattii*, but the mode of its construction is varied. The radii do not in these cases glide upon each other longitudinally, but they cross each other at various angles; and as the whole mass of these sponges is fleshy and very elastic, so by this mode of interlacement of the radii a very considerably greater amount of expansion and contraction of the reticulated structure is provided for, while at the same time the power of maintaining the common plane of the reticulated tissue is equally as great as in the similar structure in *Dactylocalyx Prattii*. Thus far we can trace the physiological purpose of their structure; but why in one species we find their terminations simple as in *Geodia M'Andrewii*, and furcated as in *Geodia Barretti*, or still further complicated as in the dichotomo-patento-ternate form, is a question which cannot be so readily solved without a further acquaintance with the species of *Geodia* bearing these forms in a living state.

The connecting spicula are not always an essential portion of the skeleton, and they exist only in comparatively a few genera of the Spongiadæ.

Prehensile Spicula.

I have so fully described, in the first part of this paper, the prehensile spicula found at the base of the beautiful *Euplectella*, in the possession of Dr. Arthur Farre, and figured in Plate XXIII. fig. 53, Phil. Trans. for 1858, as to render it necessary to say but very little more regarding them. Fig. 44, Plate XXVI. of the same paper presents so many points of structural agreement with that from *Euplectella*, as to induce a very strong suspicion of its having had a similar office to perform in the sponge from which it was obtained; but its extremely small size is against that supposition, and in favour of its being an internal defensive one. Both sponges producing these forms were parasitical on other sponges. With respect to the larger form there is no reasonable doubt of its office in the sponge, and the smaller ones may have been basal appendages to a very small species. I have searched other species of *Euplectella* in vain for similar forms.

Defensive Spicula.

The modes of defence in the Spongiadæ by means of spicula are exceedingly various, and in many cases remarkably complex and interesting. They may be divided into two great systems,—1st, those of external defence; and 2nd, those of internal defence.

If I were to attempt to enter upon a description of every variation in the mode of the application of spicula to defensive purposes, it would extend this portion of the subject to a greater length than we can afford under the present circumstances. I shall therefore confine my observations to a description of the general principles of defence as exhibited in some of the principal genera of the Spongiadæ.

In the external defences, the mode of the application of the spicula depends in a great degree on the structure of the skeleton of the sponge. The most simple cases are those where the structure of the skeleton consists of spicula radiating from the centre or the axes of the sponge, and in these cases they usually consist of the terminations of the radial lines of the skeleton, the distal spicula of which are frequently projected for a considerable part of their length through the dermal membranes, and in many sponges the surface is thus thickly studded with them; and in species where the terminal radial lines of the skeleton contain many spicula, they are frequently found at their apices to assume a radiating direction, so as to present the greatest possible number of points to their external enemies. This mode of defence is very general in the numerous British species of the genera *Isodictya* and *Chalina*, Bowerbank, MS. Fig. 10, Plate XXIX. represents a small portion of a section at right angles to the surface from *Halichondria seriata*, Johnston, *Chalina*, Bowerbank, MS., illustrating very distinctly this simple mode of external defence.

In the genus *Dictyocylindrus*, Bowerbank, MS., which consists principally of slender branching sponges, many of which in their living state are exceedingly fleshy in their appearance, the skeleton is formed of a central cylinder, composed of a network of spicula, from the surface of which radiate in vast quantities long, slender and acutely pointed spicula, which in the living condition project slightly beyond the dermal mem-

brane of the sponge, so that in the event of any small fish attempting to feed upon or suck this tempting bait, instead of a mouthful of soft and grateful gelatinous matter, he would find himself assailed in every direction with an infinite number of minute points, many of which he would carry away with him deeply imbedded in the soft lining of his mouth, as the reward of his temerity and a warning against a repetition of a like assault. Fig. 11, Plate XXIX. represents a small portion of a young branch of *Dictyocylindrus rugosus*, BOWERBANK, MS., an undescribed British species, frequently found on shells and stones dredged up at Shetland, or the Orkney Islands. In the genus *Tethea*, in which the skeleton consists of fasciculi of large, stout spicula radiating from the base or centre of the sponge, the system of defence is somewhat more complicated. It is a combination of the terminations of the skeleton fasciculi with, in some species, the addition at the surface of the sponge of porrecto-ternate and recurvo-ternate spicula; the latter two forms being probably aggressive as well as defensive, subserving the purpose of entangling prey as well as that of defence.

This mode of defence is very beautifully illustrated in *Tethea cranium*. The distal ends of the skeleton fasciculi, composed of large fusiformi-acerate spicula, are projected through the stout coriaceous surface of the sponge, and in the midst of this thick coat each of the passing fasciculi is surrounded by a cluster of stout short fusiformi-acerate spicula, their distal points closely embracing the fasciculus, while their proximal terminations are spread widely out in a circle around the lower part of the skeleton fasciculus, so as to form a strong and most efficient conical buttress to sustain it in its proper position, at the same time allowing a considerable amount of elasticity to meet pressure from without. Each skeleton fasciculus terminates with from two to eight or ten porrecto-ternate spicula, and occasionally we find one or two of the recurvo-ternate ones accompanying them; but their apices are rarely projected much beyond the dermal membrane of the sponge, while the rest of the spicula extend considerably above it (fig. 12, Plate XXIX.). The same system of defences prevails also in *Tethea simillimus*, BOWERBANK, MS., from the Antarctic regions; but in this species the recurvo-ternate spicula appear to be protruded in greater numbers and in more regular order than in our northern species, *T. cranium*.

In *Tethea muricata*, BOWERBANK, MS., the skeleton fasciculi are not protruded beyond the surface, but immediately beneath it we find the heads of numerous large furcated expando-ternate spicula, with remarkably long and acute terminal radii, while the dermal membrane is profusely furnished with attenuato-elongo-stellate spicula.

In *Tethea Norvegica* and *Ingalli*, BOWERBANK, MS., and in *T. Lyncurium*, JOHNSTON, the same protection is attained in a different manner. Instead of the spicula of the skeleton fasciculi gradually converging towards a point, they diverge considerably as they approach the surface, so as to present an infinite number of minute and nearly equidistant points, and in addition to these the dermal membrane and the coriaceous coat of the sponge is supplied with an infinite number of closely packed stellate spicula.

In some species of the genus *Geodia* the system of external defences is still more

complex. Thus in *G. M'Andrewii* and *G. Barretti* the defences are double, one system consisting of a continuation of the great radial fasciculi of the skeleton as a protection against the assaults of the larger and more powerful assailants, and then of a secondary series consisting of an infinite number of minute acerate spicula, based immediately beneath the dermal membrane and projecting to a slight extent beyond its external surface, effectually protecting it and the porous system of the sponge from the attacks of its minute and more insidious enemies.

Similar modes of external defences exist in various species of *Pachymatisma* and *Ecionemia*, but no two species appear to agree precisely in these respects.

In the genera *Microciona* and *Hymeraphia*, Bowerbank, MS., differing widely in the structure of their skeletons from any of the sponges hitherto described, and frequently not exceeding in thickness the substance of a stout sheet of paper or a thin card, the same principles of defence are carried out, although their structure is widely different from each other. In the first genus, the skeleton of which is formed of short pedestals of keratode combined with spicula, each of the pedestals, which reach nearly to the surface of the sponge, is terminated with a radiating cluster of long curved and acutely pointed spicula, the apices of which pass through the dermal membrane in every direction, and thus form a most effectual series of external defences, while their shafts beneath serve as the framework of the intermarginal cavities of the sponge (figs. 1 & 2, Plate XXX.). In *Hymeraphia*, where the sponge is less in thickness than the length of one skeleton spiculum, and where they pass from the basal membrane of the sponge through the dermal membrane, their apices acting as external defensive organs, while their shafts form the essential skeleton of the animal, there is an especial provision for their preservation from injury. Their bases are expanded in the form of large bulbs, so as not only to afford a greater surface for attachment, but to allow them at the same time to act on the principle of a ball-and-socket joint, giving them a more than usual amount of attachment, and a power of yielding in every direction to pressure on their apices from without (fig. 4, Plate XXX.). The defence of the surface of the Halichondroid sponges is less apparent, but equally efficacious; the abundantly spiculous reticulations immediately beneath and supporting the dermal membrane, would render attacks of annelids or other small predaceous creatures exceedingly unpalatable.

In the calcareous sponges the spicular defences are exceedingly interesting. In *Grantia compressa*, the distal ends of the great interstitial cells are amply protected by numerous flecto-attenuato-acuate spicula grouped around their porous terminations, with their club-shaped ends curving in every direction over them, but in no degree interfering with the freedom of their inhalant action. In *Grantia ciliata* they are grouped in circles around the distal ends of the interstitial cells, but in this species they are acutely pointed; and when the inhalant system is in a state of repose, they are concentrated at their extreme points so as to form an elongate cone, effectually enclosing and protecting the porous ends of the cells within them; but when the inhalant action is in full activity, their apices recede from each other until they assume the form of a cylinder, and then freely

admit the incurrent streams of water, but effectually repel the advances of any dangerous assailant that may attempt an entrance. The distal termination of the cloaca in this species is also abundantly protected by a marginal fringe of long and very acute spicula, and is furnished with the same simple but beautiful mechanical contrivances for opening and closing in accordance with the necessities of the animal. For a more complete description of the anatomy and physiology of this highly interesting species I must refer my reader to the 'Transactions of the Microscopical Society of London,' vol. vii. p. 79, pl. 5.

In other species of *Grantia* the same principles of external defensive action exist, but the precise mode is never exactly the same in any two species.

Internal Defensive Spicula.

The internal defensive spicula of sponges are exceedingly various in their forms and modes of application to their especial purposes; and they seem naturally to resolve themselves into three distinct groups:—1st, those which are destined simply to repel; 2nd, those which wound and lacerate as well as repel; and 3rd, those which are calculated not only to destroy but also to retain intruders.

The purposes of the first class of spicula are frequently performed by the ordinary spicula of the skeleton, which are projected more or less into the cavities immediately within the oscula and other spaces requiring such protection; but when especially formed for and appropriated to defensive purposes, they are always free from spines and usually terminate acutely; and they are frequently provided with widely extended basal radii, so as to fix them rigidly and firmly in their proper positions, as exemplified in the various forms of spiculated triradiate spicula represented by figs. 14, 15, 16, & 17, Plate XXIV., Phil. Trans. for 1858.

The best illustrations of the application of the simple defensive spicula are to be found in the cloaca in several species of *Grantia*, as in *G. ciliata*, Johnston, and *G. tessellata* and *ensata*, Bowerbank, MS. In all these species this great central cavity is abundantly furnished with spiculated triradiate spicula, such as represented by figs. 15 & 16, Plate XXIV. Phil. Trans. 1858, which are so disposed that while the basal radii are firmly cemented on the surface of the cloaca, the spicular or defensive rays are projected from its surface, not at right angles to its plane, but always at such an inclination towards the mouth of the cloaca as to present a combined series of sharp points in the best possible position of defence, so that an intruding assailant could scarcely escape being seriously wounded by them, while a retiring enemy would pass with impunity over their inclined apices. In some species, as in *G. tessellata*, the defensive ray is naturally curved to the desired angle for defence (fig. 16, Plate XXIV. Phil. Trans. 1858), and it is also of such a form as to be readily released from the creature it has wounded, either by being attenuato-acuate or ensiform, as in fig. 15, Plate XXIV. Phil. Trans. 1858, from *G. ensata*, and as represented *in situ* by a small portion of a longitudinal section of the cloaca of a specimen of *Grantia tessellata* in Plate XXX. fig. 5, in which the defensive radii are all curved in the direction of the mouth of the cloaca.

In the second division the internal defensive spicula are usually short and straight, and more or less covered with strong conical acutely pointed spines, projected either at right angles to the axis of the spiculum, or recurved considerably towards its base; generally speaking the spines are dispersed on all parts of the spiculum without any approach to order, as represented in fig. 1, Plate XXIV. Phil. Trans. 1858, while in other cases, as in figs. 2 & 3 in the same Plate, they are arranged in verticillate order on all parts of the spiculum. In each of these varieties the bases of the spicula are usually profusely furnished with spines, so as to ensure a strong and somewhat rigid mode of attachment.

There is undoubtedly a special purpose in every variation of the spination of these spicula, and in their presence generally. The short strong form and acute distal termination admirably adapt them to encounter the larger description of intruding annelids, the most dangerous internal enemies of the Spongiadæ; while the spination of their shafts presents a series of minute weapons that would prove equally formidable to those intruders that were too minute to be affected by the larger weapons of defence.

The acuate entirely spined defensive spicula are of very common occurrence in sponges, and are by no means confined to particular tribes or genera. As a general rule, when the external defences are very full and sufficient, we should not expect to find the internal defences abundant, and, on the contrary, when there appears to be a paucity of external defences, the internal ones are frequently exceedingly numerous. Thus, in the genus *Dictyocylindrus*, Bowerbank, MS., where in almost every species the surface of all parts of the sponge is bristling with the acute terminations of the radiating external defensive spicula, although in most of the species we find acuate entirely spined internal defensive ones, yet in many of the species they are so rare as to be by no means readily detected.

When the skeleton is formed of keratose fibres, we find them dispersed on their surface without any approach to order, and projected at every imaginable angle. If the skeleton be formed of any of the varieties of spicular reticulations, they are based in a similar manner on the principal lines of the reticulated structure, and sometimes, but not very frequently, they occur in groups.

I will not extend this portion of my subject to an unnecessary length by describing every mode of their occurrence, but select a few of the most interesting cases as illustrations of the general principles of their application.

Fig. 6, Plate XXX. represents a small portion of the kerato-fibrous skeleton of an Australian sponge, with the attenuato-acuate entirely spined internal defensive spicula *in situ*. Fig. 7 represents a few fibres from a kerato-fibrous sponge from the West Indies, in which the verticillately spined internal defensive spicula are dispersed over the fibres; and fig. 8 represents the same description of defensive spicula from a West Indian kerato-fibrous sponge, having the defensive spicula congregated in bundles. Sometimes, but not very frequently, they are found on the interstitial or basal membranes of the sponge, and under these circumstances many of them are prostrate in place of being erect; and in one sponge, *Hymeniacidon Cliftoni*, Bowerbank, MS., a singular parasitical species from Freemantle, Australia, this prostration appears to be effected by

an especial law. This singular sponge envelopes several fan-shaped portions of a *Fucus*, and systematically appropriates the minute ramifications of its stem to the purposes of an artificial skeleton; the whole sponge abounds with short stout attenuato-cylindrical entirely spined internal defensive spicula: but the remarkable circumstance attendant on their presence is, that wherever the membranes supporting them envelope and firmly embrace a portion of the vegetable stem, they assume an erect position, and exhibit all the usual characters of defensive spicula; but where the membranes merely fill up the areas of the vegetable network, they are nearly all of them perfectly prostrate, and apparently performing the office of tension, rather than of internal defensive spicula. Their form also is singular, being attenuato-cylindrical, not having the acute termination that is usual in this description of spicula.

Fig. 9, Plate XXX. represents a small portion of the fibrous stem of the *Fucus* coated by the membranes of the sponge, and covered with spicula; those immediately over the stem being erect, while those on the membrane are prostrate. (*a*) represents one of this new form of internal defensive spiculum $\times 175$ linear.

In *Hymeraphia stellifera*, Bowerbank, MS., an exceedingly thin coating British sponge, the internal defensive spicula present a singular variation from the normal form. In this case they assume the shape of an ordinary Florence oil flask, with a somewhat elongate neck, and having a beautiful star-shaped apex in place of a stopper. They occur in considerable quantities; their large bulbous bases are firmly attached to the strong basal membrane of the sponge, and they are projected thence at every possible angle upward into the interstitial spaces. Their apices are crowded with stout acutely conical spines, which radiate in all directions. Fig. 3 *a*, Plate XXX. represents a group of these spicula *in situ*, elevated by a grain of sand beneath the basal membrane; and fig. 4 *b*, Plate XXX., one of the same form of spiculum, magnified 260 linear. In this form of spiculum, as in that of *Hymeniacidon Cliftoni*, their purpose seems to be the infliction of laceration, rather than that of destruction, by deep wounds. In another species of *Hymeraphia*, *H. clavata*, these spicula have the same large bulbous bases as those of *H. stellifera*, but their apices are acute, like those of the normal forms of such spicula. In all these cases we observe in their attachments the same approximation to the structure of the ball-and-socket joints of the higher tribes of animals, rendering them capable of yielding in every possible direction to the struggles of any enemy with which they may be entangled.

In the third division of the internal defensive spicula there is an especial construction for retention as well as for destruction. Their apices are usually more or less hamate, as represented in figs. 7, 13, & 12, Plate XXIV. Phil. Trans. 1858, and their attachments to the sponge are usually such as to allow of a considerable amount of flexibility or motion.

I will not attempt to describe the whole of the numerous variations in the modes of their application to defensive purposes, but select a few of the most interesting cases as illustrations of the general principles of combined internal defence and aggression.

The spinulo-recurvo-quaternate spiculum, the growth and development of which I have described in the first part of this paper (Phil. Trans. 1858, p. 293), presents an admirable illustration of the combined defensive and aggressive character of some of these internal defensive spicula. The sponge in which they occur belongs to the Halichondroid tribe, the skeleton being composed of a network of spicula cemented together by their apices, which cross each other at the angles of the areas of the reticulations. The recurvo-quaternate spicula are not dispersed on all parts of the skeleton, but are congregated in groups, frequently consisting of as many as fifteen spicula, the whole of their bases being concentrated on one of the angles of the reticulations of the skeleton, while their shafts and apices radiate thence in every direction into the interstitial spaces of the sponge; they are thus placed on the strongest and most elastic portion of the skeleton, with their hemispherical bases firmly imbedded in the cementing keratode of the skeleton, which abounds at the angles of the network, and which by its inherent elasticity and strength renders the insertion of the base of the spiculum, in strength and extent of action, quite equivalent to the powers of the ball-and-socket joints in the higher tribes of animals. A small annelid or other minute intruder entangled amidst these numerous sharp hooks would struggle hopelessly in such a situation, as the spicula, from the nature of their attachment, would yield readily to its struggles in every possible direction, and at every new contortion arising from its efforts to escape it would inevitably receive a fresh series of punctures and lacerations.

Fig. 10, Plate XXX. represents a small portion of the skeleton of the sponge bearing the spinulo-recurvo-quaternate spicula *in situ*.

In other instances, where defence alone appears to be contemplated, we do not find these beautiful adaptations for motion in every direction prevail. The bases of the spicula in those cases are abundantly spinous, and are evidently intended to maintain a firm hold by their attachments, and are destined rather to rigidly maintain their position than to yield to any struggling body with which they may be in contact. The numerous spines with which these shafts are frequently covered are calculated to wound and lacerate, rather than to retain the enemies with which they are engaged*.

* Since I wrote the first portion of this paper, I have received from my friend, Mr. J. Yate Johnson, of Madeira, a new and very illustrative instance of the combination of defence and aggression in the structure and offices of the internal defensive spicula; and in this case it is not a new organ, but an adaptation of a well-known form to a new purpose, in the shape of a contort trenchant bihamate spiculum of unusual size and structure. In the course of my examination of the results of the deep-sea soundings in the Atlantic, I found several of these spicula, and was much interested by the singularity of their structure, which at that time I could not comprehend.

The general outline is much like that of the type-form so commonly found imbedded in the sarcode, but it is somewhat less flexuous in its curves, and the shaft and hami are very much larger and stouter than those of the spicula of the sarcode. But the most singular point in their structure is, that while the curved portion of the hami and the middle of the shaft are perfectly cylindrical, the inner portion of the hooks and those parts of the shaft immediately opposed to them present sharp trenchant edges, so that each hook assumes to some extent the form of spring hand-shears. The acute termination of the hook and the opposed trenchant edges exhibit every facility for effecting an entrance through the tough skin of the victim, while

In *Hyalonema mirabilis*, GRAY, a sponge nearly related to the genus *Alcyoncellum*, QUOY et GAIMARD, we find another extraordinary series of internal defences; one portion of the spicula appearing to be destined to wound and lacerate, rather than to retain intruding enemies, while a larger and stronger series of spicular weapons bear all the evidences of being to retain rather than to repel the assailants.

The first description of spiculum I have designated entirely spined, spiculated cruciform spicula. They consist of a short stout cruciform base with a long spicular ray, ascendingly and entirely spinous, projected at right angles from the centre of the basal radii. The spines are acutely conical, and very sharply pointed. They pass off from the spicular ray at an angle of 12 or 15 degrees in the direction of its apex. The apices of the basal radii are attenuated and slightly spined. These spicula are thickly distributed on the fasciculi of the skeleton, and frequently equally so on one side of the interstitial membranes, probably that which forms the surfaces of the interstitial spaces, and they are especially abundant near the exterior of the sponge. The four basal radii appear firmly cemented to the membrane, but not immersed in its substance, as they do not appear to leave their impressions when removed from it, nor do they bring any portion of the membrane away with them. In some parts of the tissue these spicula are very much modified in form. In the ordinary cases we find the basal radii short and stout, and not more than a fourth or a fifth of the length of the spicular ray, while in other cases the basal rays are very nearly as long as the spicular one; the only difference in their structure being that the latter is very strongly spinous, while the former have the spines comparatively very slightly produced.

The second form is a large fimbriated multihamate birotulate spiculum, which occurs dispersed amid the interstitial tissues of the large basal mass of the sponge. There are usually not more than one or two together, but occasionally they occur in groups of ten or twelve, without any approach to definite arrangement.

These spicula are comparatively large and stout. They have eight rays at each end of the shaft; the two groups of radii curving towards each other to such an extent that each

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the perfectly blunt and cylindrical state of the arch of the hook bespeaks the design of retention as well as of destruction. As soon as the hook has penetrated to the inner blunt surface of the curve, it no longer cuts, and the prey, wounded in every direction, is securely retained for the nutrition of the sponge. This result is indicated not only by the form of the spicula; their position in the structure of the sponge bespeaks their office equally unmistakeably. They are not immersed in the sarcode like their congeners in form, but are firmly cemented by one hook to the reticulating lines of the skeleton, while the other ends are projected at various angles into the interstitial cavities of the sponge in such numbers and in such a manner, that it would be next to impossible for an intruder within the sponge to escape being entangled and destroyed amongst them. Fig. 1, Plate XXXI. represents a portion of the reticulated skeleton of the sponge with the trenchant contort bihamate spicula *in situ*, magnified 50 linear; and fig. 2 one of the spicula, magnified 400 linear, to exhibit the trenchant edges and the cylindrical portions of the hami and shaft.

This sponge is allied to *Halichondria* by the structure of the skeleton, and it is described by my friend Mr. J. YATE JOHNSON as being a thin coating species, spreading over the surface of rocks and stones to the extent of two or three inches in diameter.

forms the half of a regular oval figure; the opposite apices being separated to the extent of about the length of one of the radii. Each ray is in form like a double-edged blunt-pointed knife, bent near the handle in the direction of a line at right angles to one of its flat sides; and each ray is strengthened and connected with the shaft of the spiculum by a stout curved web of silex, which extends from a little below the inner surface of the ray to a point on the shaft about opposite to its middle. The shaft is cylindrical, and has short stout tubercles dispersed over all its parts when fully developed.

The structure of every part of this singularly beautiful spiculum is strikingly indicative of its office in the economy of the sponge; the form and mode of bending of the radii, with their thin edges at right angles to the line of force in a struggling animal, and the powerful web at the base of the ray enabling it to sustain an amount of stress that the unsupported flat ray would never otherwise be able to endure.

The spiculated cruciform spicula are exceedingly abundant in every part of the sponge, and no victim entangled and retained by the large multihamate spicula could avoid innumerable wounds while struggling to effect its escape; while the one held it secure within the sponge, the others, from the peculiarity of their form and mode of disposition of their acutely pointed spines, would readily release it after the infliction of every puncture, only that the wounds might be multiplied until the creature was pierced in every part, and bled to death for the nutrition of the sponge.

Fig. 3, Plate XXXI. represents a small portion of the skeleton of the sponge with the two forms of defensive and aggressive spicula *in situ*, magnified 50 linear. Fig. 4 represents one of the multihamate bihamate spicula with a power of 83 linear, displaying the adaptation of its structure to purposes of retention. Fig. 5 represents one of the spiculated cruciform spicula on the same scale as fig. 4, showing their relative proportions, and fig. 6 the same form of spiculum with a power of 260 linear, to exhibit the peculiarities of its spination.

It would be almost an endless task to describe every variety of these singularly beautiful contrivances for combined defence and offence in the interior of the Spongiadæ. Those which I have particularized are some of the most elaborate and beautiful that I have seen during the course of my researches. In many other cases, where all that is required is defence, the means employed are of a much more simple nature. We find in the Spongiadæ, as in other animals, that nature frequently economizes her means by the conversion of one organ to the purposes of another by slight adaptations or additions; thus in *Halichondria incrustans*, JOHNSTON, and in other sponges, the skeleton spicula are made to perform the duties of internal defensive spicula, by being more or less furnished with spines, as represented in fig. 30, Plate XXIII. Phil. Trans. 1858, and in other cases we find them medially or apically spined, as in figs. 32, 33, & 34 of the same Plate.

In like manner we find the spicula of the sarcode, by the extreme profusion in which they occur in that substance near the surface of some sponges, are turned to good account for the general purposes of external and internal defence, as well as for their special purpose of the protection and support of the sarcode. So likewise in the tension

spicula of *Spongilla lacustris* (fig. 21, Plate XXIV. Phil. Trans. 1858) they are made to serve as defensive organs as well as tension spicula; and, again, in the spicula of the gemmules of the Spongiadæ their skeleton spicula also perform the office of defensive organs as well, as represented by figs. 13 to 43, Plate XXVI. Phil. Trans. 1858.

As regards, then, their protection from their enemies, there appears to be almost a natural prohibition to the sponges becoming, to any great extent while alive, the food of other creatures. The keratode of their skeletons appears to be almost indestructible by maceration or digestion, and the abundance of the acutely pointed spicula that exist in so many of their bodies must render them anything rather than desirable or digestible food to the generality of other marine animals; and, in truth, I do not know of a single large fish, or other marine creature, that appears to prey upon them. The only animal in the stomach of which I have ever seen the spicula of any sponge was a *Doris*. But although appearing to enjoy almost an immunity from the common lot of animals, that of being eaten by others, they may yet serve, at their death by natural causes, to supply an immense quantity of animal molecules for the sustenance of the myriads of minute creatures that exist around them.

Tension Spicula.

The primary purpose of the tension spicula is that of strengthening and supporting the membranes, both external and internal. They are usually of the same form as those of the skeleton, but more slender and shorter in their proportions. On the internal membranes they are dispersed without any approach to order, and cross each other at every imaginable angle. They vary exceedingly in length and diameter, and are attached for their whole length to the tissues on which they repose. In some cases they are not readily to be distinguished from those of the skeleton, as they are frequently so nearly of the same size, and are intimately intermingled with them, as in the genus *Hymeniacidon*; but in other cases, as in some species of *Chalina* and *Isodictya*, they may always be distinguished by their position, and by the total absence of keratode around them, while those of the skeleton are always more or less coated by that substance.

In other cases they differ materially in form and proportion from those of the skeleton. Thus in *Halichondria incrustans*, while the skeleton spicula are stout, short, entirely spined and acuate, as represented by fig. 30, Plate XXIII. Phil. Trans. 1858, the tension spicula are smooth, slender mucronato-cylindrical, as represented by fig. 23, Plate XXIV. Phil. Trans. 1858. They are frequently dispersed on the dermal membranes, much in the same manner as they are on the interstitial ones, abounding most where the areas are largest, and where the areas are small they are few in number or entirely absent; but in other cases, as in the dermal membrane of *Halichondria incrustans*, they are congregated in flat broad fasciculi, which are disposed on the membrane with little or no approximation to order.

The tricurvo-acerate form in all its varieties is better calculated to effect their peculiar office in small and irregular spaces, and with greater economy in numbers, than the

straight elongated forms; and they are also better adapted to membranes having unequal surfaces, such as those in *Microciona armata*, Bowerbank, MS., where we see them following the undulations of the membranes and sustaining them in their proper positions around the columnar parts of the skeletons. The varieties of form in these spicula are well represented by figs. 26, 27, & 28, Plate XXIV. Phil. Trans. 1858. They are all out of the same sponge. In *Grantia compressa*, and other closely allied species, where the structure is systematically membranous, the skeleton spicula are triradiate, supporting the membranes in uniform planes in the most effectual manner; and they are, in fact, systematically tension spicula, as well as skeleton ones. In *Grantia nivea*, Johnston, which is not symmetrical in its structure like *G. compressa* and its congeners, other forms of tension spicula are developed to suit their especial purposes, such as represented by figs. 30 & 31, Plate XXIV. Phil. Trans. 1858.

In siliceous sponges we also occasionally find triradiate spicula developed, and performing the office of tension spicula, in the midst of comparatively large membranous areas; but these forms, in every case under such circumstances in which I have seen them *in situ*, appear to belong to the exception, rather than the general rule obtaining in such sponges.

The foliato-peltate spicula, for a full account of the progressive development of which I must refer to page 298, Phil. Trans. 1858, appear to be a development of the apices of connecting spicula into dermal tension ones, bearing a strong resemblance in form and purpose to the bony scutes in the skins of some of the higher animals, while the extreme crenulation of their margins probably served the purpose of facilitating the action of the porous system.

In all the varieties in form which I have hitherto described, and with which I am acquainted, where they perform the office of tension spicula only, they are destitute of spines. In other cases the tension spicula not only fulfil their own especial office, but they subserve that of defensive spicula also. Thus in the dermal membrane of *Spongilla lacustris*, Johnston, we find them dispersed rather numerously, covered with short acutely conical spines, as represented by fig. 21, Plate XXIV. Phil. Trans. 1858. In *Spongilla alba*, Carter, we find the tension spicula as abundantly spinous as those of *S. lacustris*, but in this case the spines are truncated (fig. 22, same Plate). They have a similarly blunted, imperfectly produced character in those of *Pachymatisma Johnstonia*, as represented by fig. 24.

The production of tension spicula in the membranes of the Spongiadæ is by no means a peculiarity of that class of animals. We find them in numerous beautiful forms in the skins of the Holothuriadæ, varying in shape in the different parts of the animal to adapt themselves to the necessities of their situation; but the closest approximation, both in size and form, to those of the Spongiadæ are the bihamate ones that are found so abundantly dispersed on the membranous tubular suckers of *Echinus sphæra*; and I have also seen another variety of these spicula in the tubular tentacles of a large common species of *Actinia*, and in the latter case they were even more minute than those of the Spongiadæ.

Retentive Spicula.

In the first part of this paper (Phil. Trans. 1858, p. 300) I have described the varieties in form and modes of development of these spicula. However varied they may be in form, when they are in their normal positions their office appears to be purely retentive. They are generally produced singly, and are dispersed without any approach to regularity over all parts of the sarcodous membranes of the sponge, abounding in some situations to a very much greater extent than in others. Their positions on, and mode of attachment to, the membrane are exceedingly varied, but in almost every instance it is such as to render the spiculum obviously subservient to the retention of the sarcode on the membranes which it covers. In one instance only I have found the simple bihamate spicula congregated in loose fasciculi. In this sponge, a new and very interesting species, *Hymedesmia Zetlandica*, Bowerbank, MS., they occur in great profusion. Very few of them occur singly; nearly the whole of them are found in rather loose fasciculi, and the number is generally so great in each as to render it very difficult or impossible to count them. The mode of their disposition in the bundles is symmetrical, all the hami being in the same plane and coincident in direction, as represented in Plate XXXI. fig. 8. A few bundles of reversed bihamate spicula were observed, and these in like manner were coincident in every respect like the simple bihamate ones.

When these forms of spicula are equal in the amount of the development of their terminations, and when their hami or palms are coincident in plane and direction, their normal mode of attachment is at the middle of the bow of the shaft, and the direction of their projection is at right angles to the plane of the membrane on which they are situated, so that both terminations are rendered effective as retentive organs, as represented in fig. 8, Plate XXXI., dispersed on the membrane. But when their terminations are in different planes, or unequal in amount of development, then the normal mode of attachment to the membrane is by one end of the spiculum, while the other end is projected into the sarcode above at various angles. This mode of disposition of the inequianchorate form of spiculum is beautifully illustrated in *Halichondria lingua*, Bowerbank, MS., a new species of British sponge from the Hebrides.

In this case, as in *Hymedesmia Zetlandica*, we find these organs congregated, but in a very much more symmetrical and beautiful mode. They occur in rosette-shaped groups; the smaller palms being adherent to the membrane in a circular form, and disposed as close to each other as possible, while the larger palms radiate from the centre at angles of about 20 or 30 degrees from the plane of the membrane beneath, as represented by fig. 9, Plate XXXI.

I have selected this group for representation in consequence of its containing but a small number of spicula, and thus displaying the mode of arrangement more distinctly than a greater number would have done. In many cases these groups contain so large a number of spicula as to render any attempt to count them ineffectual, and in some instances so many are developed that the group assumes the form of a ball rather than

that of a rosette. Fig. 10, Plate XXXI. represents a rosette-shaped group containing about the usual number of spicula.

Besides the rosette-shaped groups in *Halichondria lingua*, there are a considerable number of these spicula dispersed over the surfaces of the membranes; but the attachment of these spicula is more frequently at the middle of the shaft than at the smaller end of the spiculum, their normal point of attachment. In the single and separate mode of disposition they are performing the office of equi-anchorate spicula, and the mode of their attachment is varied accordingly; but under these conditions they are rarely ever so fully developed, nor do they attain the same size as those which form the radiating groups. Notwithstanding the numerous groups and dispersed spicula of the inequi-anchorate form, this sponge is also abundantly furnished with bihamate spicula of various forms, but they are never congregated like the anchorate ones.

The same radiating mode of arrangement occurs in a parasitical Australian sponge from Freemantle, but the form of the terminations of the spicula is very different from those of *Halichondria lingua*. The distal termination of each of the inequi-anchorate spicula is shortened in length, but expanded laterally to a considerable extent, and its terminal edge is furnished with three thin pointed teeth. The distal end has two small expanded and raised wings, projected in the direction of the inner curve of the spiculum, and so disposed as to cause it to resemble very closely an engineer's spanner for bringing up to their bearings projecting square-headed screws. Thus, although the forms of the termination of the two varieties of spicula vary to a considerable extent, the principles of their structure and purposes are in perfect unison. Fig. 11, Plate XXXI. represents a group of these spicula, and fig. 12, Plate XXXI. a single spiculum highly magnified to display their peculiarity of structure.

These forms of spicula appear to be peculiar to the siliceous sponges. I do not recollect having ever seen them in any species of calcareous sponge.

Spicula of the Sarcode.

The primary office of the whole tribe of multiradiate spicula is evidently that of consolidating the sarcodous substance of the sponge, nor is their presence in the exercise of this office confined to the Spongiadæ. In the soft parts of the extensive family of the Gorgoniadæ we find them in vast abundance, and in every variety of form, from an elongate tubercular spiculum to the elongo-stellate forms of the Spongiadæ, and the prevalence of the bluntly terminated radii is strongly indicative of their non-defensive character. But this latter quality does not obtain in other cases, either as regards the higher tribes of animals or the Spongiadæ. Thus we find in numerous species of compound tunicated animals their fleshy substance is crowded with sphero-granulate spicula, very closely resembling in form those of the sphero- and subsphero-stellate shapes so abundant in *Tethea Ingalli* and *T. robusta* (figs. 14 & 15, Plate XXV. Phil. Trans. 1858). In both these cases the acute termination and the peculiarities of their respective situations are indicative of their subserving the office of defensive, as well as that of consolidating spicula.

In some species of *Tethea*, where the sponge is elaborately protected by distinct systems of defensive spicules, the subsphero- or sphero-stellate forms are either entirely absent, or only represented by minute clavate or cylindro-stellate forms; but in *Tethea Ingalli* and in *Geodia carinata*, where there is an almost total absence of elongate defensive spicula at the surface of the sponge, the acutely pointed large subsphero-stellate spicula are exceedingly numerous immediately beneath the dermis, and gradually decrease in number in an inward direction until they almost cease to exist in the deeper portions of the sponge. Thus their presence in such abundance near the surface of the animal would tend materially to check the voracity of any enemy that might attempt to prey upon them. In like manner we find the smooth and abundantly porous membrane of *Tethea muricata* (figs. 14 & 15, Plate XXXI.) crowded with the elongo-attenuato-stellate form represented in Plate XXV. fig. 18, Phil. Trans. 1858; and a single glance at them, as represented *in situ*, will show how admirably they are calculated to defend the delicate tissue on which they repose from the attacks of even their most minute and insidious enemies. The mode of their disposition is also strongly indicative of their defensive functions, their long axis being, not parallel to the plane of the membrane beneath, but at right angles to it.

In *Tethea Norvegica*, Bowerbank, MS., where the surface of the sponge is well provided with external defensive spicula, the large subsphero-stellate form is comparatively rare, but the tissues of the neighbourhood of the intermarginal spaces and canals are crowded with the minute attenuato-stellate forms, and their surfaces are bristling with the sharp points of their radii, so that no intruding annelid could either take a mouthful from their surfaces or crawl over them with impunity. Deeper in the sponge, beyond the range of penetration of such enemies, they are comparatively very few in number, and the large subsphero-stellate ones are entirely absent.

The hexradiate forms represented by figs. 24 to 36, Plate XXV. Phil. Trans. 1858, are more especially found in the siliceo-fibrous sponges. I have only seen two specimens of this class of sponges in which the sarcode was well preserved. In one of these I have observed the slender form like that of fig. 34, Plate XXV., occupying the areas of the rigid siliceous skeleton completely surrounded by sarcode, which stretched from one ray to another in thick glutinoid plates, but without touching the surrounding skeleton-fibres, excepting at one basal point connecting it with the general mass of the sarcodous tissues. From the positions and general appearances of the hexradiate spicula, it would appear that this form of spiculum has the office more especially of supporting and consolidating the sarcode, and that it is in no respect subservient to defensive purposes.

Generally speaking the slender rectangulated hexradiate spicula occur singly, but I have sometimes found them grouped together; in this case their axes were coincident, and their radii in the same plane, or very nearly so, but not always agreeing in their direction; such a framework would form a very fitting support to a large mass of sarcodous tissue partially separated from the framework of the skeleton and occupying a portion of a large interstitial space.

In the large open areas of the skeleton of *Euplectella aspergillum*, Owen, the hexradiate forms, ranging from fig. 24 to fig. 33, Phil. Trans. 1858, are exceedingly abundant, and a considerable number of them are not developed to the extent of the full number of their radii. This may probably arise from the development of the radii being stimulated by the necessities of the mass of sarcodous tissues in which they are imbedded, and consequently where no necessity for their presence exists they would not be put forth. In the trifurcate and quadrifurcate hexradiate forms, if we may judge from the termination of their radii, they, like the simple stellate forms, are either purely consolidating, or they combine with that office that of defensive spicula also, as far as regards the sarcodous substance in which they are imbedded.

We can scarcely imagine any defensive properties in the slender and complicated but elegant forms of the floricomo-stellate spicula, and it is probable that their office is purely that of assisting in the consolidation of the sarcodous substance.

The whole of these beautiful stellate forms of spicula are siliceous, while their homologues in the Gorgoniadæ and the compound Tunicata are calcareous; and it is somewhat remarkable that hitherto none of these forms have been found in the calcareous species of sponges.

Spicula of the Ovaria and Gemmules.

We find the same laws in force regarding the spicula in the structure of the minute bodies which have been designated gemmules by previous writers on the Spongiadæ, that obtain in the sponges themselves. In some they serve the purposes of internal skeleton and defensive spicula as well. In others they combine the offices of tension and defensive organs, and frequently they are very different in form from those of the parent sponge. In the first part of this paper, in Plate XXVI. figs. 11 to 42, Phil. Trans. 1858, I have figured the varieties of form that I have hitherto found in the ovaria and gemmules, and I have shown that these bodies may be classed in three groups.

1. Those which have the spicula disposed at right angles to lines radiating from the centre of the ovarium to its surface.

2. Spicula disposed in lines radiating from the centre to the circumference of the ovarium.

3. Spicula disposed in fasciculi in the substance of the gemmule from the centre to the circumference.

In *Spongilla Carteri*, Bowerbank, MS., and *S. fluviatilis*, Johnston, our commonest British species, belonging to the first group, the external series of spicula of the ovaria are of the same form as those of the skeleton, but frequently somewhat shorter. They are disposed irregularly over the surface of the ovarium, and firmly cemented to it by the middle of the shaft, while each of their apices is projected in tangental lines. Thus their shafts perform the office of tension spicula, while their terminations become efficient weapons of defence. Fig. 11, Plate XXVI. Phil. Trans. 1858, represents the spiculum of the ovarium of *S. Carteri*.

In other cases in this group we find these spicula differing from those of the skeleton

of the parent sponge; thus, the one that is represented by fig. 13, Plate XXVI. Phil. Trans. 1858, from the surface of *Spongilla lacustris*, JOHNSTON, is curved so as to accommodate it to the rotundity of the ovarium; and we do not find its apices projecting as in those of *S. fluviatilis*, but instead of the projecting apices, the whole spiculum is covered with minute spines, assimilating it in character with the general structure of those spicula which combine the office of tension and defensive spicula, but differing considerably in their proportion from the tension spicula of the same sponge, *S. lacustris*, represented by fig. 21, Plate XXIV. Phil. Trans. 1858, the one being evidently destined to sustain and protect extended membranes, while the other is especially adapted for a small curved surface by its form and small size; each of the figures being drawn with the same power, 660 linear.

On the surface of the ovarium of *Spongilla cinerea*, CARTER, we find this description of spiculum still more decidedly produced. It is of a cylindrical form and entirely spined, and has just the amount of curvature that is in unison with the curved surface on which it reposes. The spines on the middle of the shaft are cylindrical, and terminated bluntly, so as to strengthen its hold on its imbedment. Those of its apices, on the contrary, are acutely conical and recurved, and are strongly produced, so as to form very efficient weapons of defence. This spiculum is represented by fig. 17, Plate XXVI. Phil. Trans. 1858.

The birotulate and boletiform spicula of the second group appear to be more purely structural, as regards the skeleton of the ovarium. The rotulæ are very closely packed at both the external and internal surfaces of that body, and the crenulation or dentation of each rotula is as well produced on the internal as on the external ones, and it appears to be very influential in maintaining each spiculum in its proper position. In the natural condition of the ovaria these spicula are entirely imbedded in its walls, and other spicula of a truly defensive nature are superimposed for its protection. The large spines in the shafts of the birotulate spiculum from *Spongilla plumosa*, CARTER, fig. 21, Plate XXVI. Phil. Trans. 1858, are also apparently subservient to strengthening and maintaining the spiculum in its proper situation, although they are acutely terminated, as defensive spines usually are; but in the same relative position on the birotulate spicula of *Spongilla Meyeni*, CARTER, we find the spines short, stout, and cylindrical, spreading or budding at their apices, and evidently more fitted for assisting to retain the spiculum in its proper place than for defensive purposes. This spiculum is represented by fig. 29, Plate XXVI. Phil. Trans. 1858.

There is an apparent analogy between the expansions of the rotulæ and those of the folio-peltate spicula, but they do not appear, like the latter, to be derived from the ternate forms. The radiations of the canaliculi, as represented by fig. 32, Plate XXVI. Phil. Trans. 1858, are not derived from three primary rays, but each appears to emanate from a central cavity at the end of the shaft; and their number, 22, at their proximal termination is not reconcileable with any regular number of bifurcations arising from three primary rays, however short we may imagine them to be.

The progressive decline of the inner rotula in the inequi-birotulate spiculum of *Spongilla paulula* (fig. 31), and its all but total extinction in *Spongilla reticulata* and *Spongilla recurvata* (figs. 33 & 34) until the distal rotula merges in the scutulate form, with an acute external umbo in place of an internal shaft as in *Spongilla Brownii*, figs. 36 & 37, Phil. Trans. 1858, exhibit a very interesting series of gradations of development in the same description of organ.

The spicula of the third group (those having the spicula disposed in fasciculi in the substance of the gemmule) differ less in character from those of the parent sponge than either of the preceding groups. They are in reality but modifications of the external defensive spicula of the parent sponges.

The inequi-fusiformi-acerate one (fig. 39, Plate XXVI. Phil. Trans. 1858) differs from the fusiformi-acerate one of the skeleton in no other respect than in the greater proportionate attenuation towards its distal termination, which gives it a degree of flexibility that allows of its bending freely under the pressure of any comparatively large body; and I have seen them, when two gemmules have been pressed closely together, bent to the extent of semicircles without breaking. In the young gemmules these spicula are usually projected much beyond the other forms of defensive spicula that accompany them.

In like manner the small attenuato-porrecto-ternate form (fig. 43, Plate XXVI. Phil. Trans. 1858) is a modification of the similarly formed external defensive spicula of the parent sponge. In the adult gemmule the apices of these spicula rarely project beyond the dermal membrane, and it is only on pressure from without that they would be brought into effective use. The amount of the angle of their radiation at the apex of the spiculum is therefore greatly increased beyond those of the external defensive ones of like form in the parent sponge, so as to accommodate their apices to the curve of the surface of the gemmule, and to render each point equally effective; and as they are not projected beyond the dermal surface, as in the sponge, their shafts are shortened proportionally.

The unihamate, bihamate, and recurvo-ternate forms of the same gemmules (figs. 40, 41 & 42, Plate XXVI. Phil. Trans. 1858) are also modified forms of the recurvo-ternate external defensive spicula of the parent sponges, *Tethea cranium* and *simillimus*.

Of the other forms of "spicula the position of which are unknown," I can say little more than I have before stated, excepting that I have since found the subspinulato-arcuate one, represented by fig. 51, Plate XXVI. Phil. Trans. 1858, *in situ* in a new species of sponge from Freemantle, Australia, *Hymeniacidon Cliftoni*, Bowerbank, MS., and that it is a retentive spiculum.

The Interstitial Canals and Cavities.

These organs exhibit their most complete mode of development in the genus *Spongia* and in the Halichondroid sponges, occupying nearly the whole of the masses of the animals. They consist of two distinct systems, an incurrent and an excurrent one.

The incurrent series have their origin in the intermarginal cavities immediately within the dermal membrane, and their large open mouths receive from these organs the water inhaled through the pores and convey it to the inmost depths of the sponge, ramifying continually like arteries as they proceed in their course downward until they terminate in numerous minute branches. The inhaled fluid is then taken up by the minute commencements of the excurrent series, which continually unite as they progress towards the surface of the sponge, in the manner of veins in the higher animals, until they terminate in one or more large canals which discharge their contents through the oscula of the sponge. This system is found to obtain in the whole of the genus *Spongia* and in the massive Halichondroid sponges, which have their oscula dispersed over their external surfaces. By this mode of organization the inhaled fluid, laden with nutritive particles, is poured at pleasure into the internal cavities of the sponge, flowing over extensive membranous surfaces coated with sarcode; so that the aggregated surfaces become a great system of intestinal action, fully equal in proportional extent to that of the intestines of the most elaborately organized mammal.

They do not in every genus exhibit the regularity of structure described above, and in some cases the canalicular form resolves itself into a series of irregularly formed spaces. In other cases, where a common cloaca exists, there appears to be but one system of interstitial canals, those which convey the inhaled fluid from the pores through the substance of the sponge to the parietes of the great central cloacal cavity which receives the whole of the fæcal streams, rendering the system of excurrent canals unnecessary.

In the Cyathiform sponges we find a somewhat slmilar structure. The outer portion of the cup is essentially the inhalant surface and the interior of it the exhalant one, and there accordingly we generally find a great number of small oscula dispersed on all parts of it, very often having their margins slightly elevated, that the fæcal matter that issues may be discharged free of the surrounding membrane.

The large fistular projections which form such striking and beautiful objects in the genus *Alcyoncellum* are also great cloacal organs, their dermal membranes abounding in pores, and their inner surface furnished with oscular orifices, the intervening space being occupied by the interstitial cavities, the interior forming one large cloacal cavity, which discharges its contents through a cribriform mouth at its distal end. In *Grantia* both systems, the incurrent and excurrent interstitial canals, become very nearly obsolete, the large intermarginal cavities or cells imbibing the water through their pores on the distal extremities, and becoming enlarged and elongated until they reach the parietes of the great central cloaca, into which they discharge their contents, each through a single osculum, into a short depression or cavity in the parietes of the great cloaca, and this shallow cavity represents the nearly obsolete system of excurrent canals.

The membranes lining the incurrent and excurrent canals are frequently highly organized. In the common honeycomb sponge of commerce, when in the same condition as when taken from the sea, these canals are constructed of a series of compound

membranes, each consisting of simple interstitial membrane with a layer of primitive fibrous tissue beneath it; the fibrous portion consisting of a single series of fibres parallel to each other, and so closely adjoining as to touch each other through nearly their whole course (Plate XXVII. fig. 4).

When the fibres are clear of the membranous tissue they appear as simple pellucid threads, but when covered by the membrane they frequently appear as if moniliform; this character seems to be due to minute molecules arranged in linear series on the membrane immediately above them. These membranes abound in large open oval spaces, so that the tissue assumes very much the appearance of areolar tissue, as described by Professor BOWMAN in his treatise on mucous membrane in the 'Cyclopædia of Anatomy and Physiology.'

The layer of membrane forming the surface of the canal has its fibres disposed at right angles to the axis of the canal, while those of the layers beneath it assume various directions, usually in straight lines, excepting in the vicinity of the areas of communication, around which they curve to strengthen their margins.

In the canals deeply buried in the mass of the sponge, the sides frequently consist of but one layer of membrane and primitive fibrous tissue, and in this case also the fibres are always disposed at right angles to the axis of the canal, but they are neither so numerous nor so closely packed as in the sides of the great excurrent canals.

The interstitial membranes are also furnished with these fibres, sometimes in considerable quantity, but rather irregularly disposed, while in other cases a single fibre only will be observed meandering across the tissue.

The interstitial membranous tissues in a beautiful little specimen of *Alcyoncellum* from the North Sea, for which I am indebted to my friend Captain THOMAS of the Hydrographical Survey, are very similarly constituted to those of the sponges of commerce. The membranous walls of the interstitial cavities are each formed of a series of fibro-membranous layers, the fibres of each layer being disposed at angles varying from those above and below it.

Figures 1, 2, 3, & 4, Plate XXVII. represent portions of the lining membranes of the incurrent and excurrent canals, and the mode of the disposition of the primitive fibrous structure upon them.

Intermarginal Cavities.

In the Halichondroid sponges, immediately beneath the dermal membrane, there are numerous and, comparatively speaking, large irregularly formed cavities which receive the water inhaled by the pores, and convey it to the mouths of the incurrent canals, which have their origin in the deepest portions of the spaces. These organs, from their irregularity in size and form, are not always very apparent; but if a section be made at right angles to the surface in a dried specimen of *Halichondria panicea* or *Hal. simulans*, JOHNSTON, they may be readily detected and distinguished from the interstitial canals and spaces of the sponge.

Fig. 13, Plate XXXI. represents a section of *Halichondria panicea*, and fig. 1,

Plate XXXII. a similar section of a branch of *Halichondria simulans*, JOHNSTON, showing that, however varied the forms of the sponge may be, the interstitial cavities are the same in structure and position.

I have never been able, in the Halichondroid sponges, to detect valvular diaphragms separating these spaces from the interstitial canals and cavities beneath.

In the genera *Geodia* and *Pachymatisma* these organs assume a very much greater degree of regularity and a complexity in their organization that are never apparent in those of the Halichondroid sponges. In *Geodia Barretti*, BOWERBANK, MS., a highly organized species of the genus, they are found in the crustular dermis in great abundance. They are in form very like a bell, the top of which has been truncated. They are situated in the inner portion of the dermal crust; the large end of the cavity being the distal, and the smaller end the proximal one. The open mouth or distal end of the cavity is not immediately beneath the dermal membrane. There is an intervening stratum of membranes and sarcode, of about two-fifths the entire thickness of the dermal crust, which is permeated by numerous minute canals which convey the water inhaled by the pores to the expanded distal extremity of the cavity. The proximal end is closed by a stout membranous valvular diaphragm, which the animal has the power of opening and closing at its pleasure. It is usually entirely destitute of the characteristic dermal spicula that are found abundantly in the adjoining membranous tissues.

The action of the diaphragm of each cavity appears to be independent of the surrounding ones, the condition or degree of opening of no two adjacent ones being alike. In the greater number of cases they were in a closed state, and in this condition the membrane was filled with concentric circles composed of minute rugæ or thickened lines, and at the centre it was closely pressed together, completely closing the orifice. In some cases the membrane was only partially closed, and the orifice was either circular or slightly oval; in others it was nearly as large as the diameter of the basal end of the cavity. The pursing of the centre of the membrane of the diaphragm was always outward as regards the cavity, so that when viewed from within it appeared as a slightly funnel-shaped depression, the bottom of which was conical. The cavities are lined by a smooth and tolerably strong membrane, abundantly supplied with slender fibrous tissue, disposed in nearly parallel lines at right angles to the long axis of the cavity.

The adaptation of the skeleton to the support of these elaborately constructed organs is very remarkable. The sponge is furnished abundantly with large expando-ternate spicula, the radii of which are furcated at their apices. They occur in a series of bundles; the long attenuated shafts of each fasciculus approximate at their bases, and diverge thence until the ternate head of each is about equally distant from its surrounding neighbours, and the extremities of the rays touch or slightly cross each other, thus forming a beautiful and regular network, the meshes being six- or seven-sided, according to circumstances. The upper surfaces of the radii are firmly attached to or partially imbedded in the under surface of the crustular stratum, and the areas thus formed are occupied each with the proximal valvular terminations of one of the intermarginal cavities.

The progressive development of these inhalant areas, formed by combinations of the radii of the ternate forms of spicula, in different species of sponges is very interesting. In *Pachymatisma* they are so indefinite that they can scarcely be said to exist. The ternate spicula are few in number and very irregular in their mode of disposition, and a faint indication only of their future regular combination to form the dermal reticulation is apparent. In the more highly organized genus *Geodia* we find them in different species in progressive stages of combination, until, in *G. M'Andrewii* and *Barretti*, the apices of the radii of the ternate spicula are interlaced with each other, and a continuous irregular network is formed, each area of which is filled with the proximal termination of an intermarginal cavity. In *Dactylocalyx Prattii*, Bowerbank, MS., the structure advances another stage towards perfection.

There is the same design as that exhibited in the construction of the dermal areas in *Geodia M'Andrewii* and *Barretti*, but there is a considerable difference in the application of the areas produced by the combinations of the ternate apices. In *Geodia* these areas are placed beneath the highly organized and regularly formed intermarginal cavities, and form the framework and support of their valvular proximal ends; while in *Dactylocalyx Prattii* they are situated above the distal ends of the intermarginal cavities of the sponge, which have not the regular structure and valvular appendage of those of *Geodia*, but are similar to the like organs in the Halichondroid sponges, and in this position they serve only to support and strengthen the dermal membrane, which adheres firmly to their distal surfaces. In this situation they are subject to a greater chance of pressure and disruption than the more deeply seated ones of *Geodia*, and accordingly we find extra provisions for the safety of the junctions of their radii. The shafts of these spicula are short, stout, and conical, and they penetrate but a very short distance into the substance of the sponge. They do not appear to be cemented to any part of the rigid siliceo-fibrous skeleton, but are merely plunged into a somewhat thick stratum of membranous structure reposing on the surface of the skeleton. Their radii are compressed considerably and extended laterally, so that their planes are in accordance with that of the dermal membrane, and they present a greater amount of adhesive surface than those having cylindrical radii. The ternate rays ramify irregularly. Sometimes one ramus, after slightly pullulating, remains nearly obsolete, causing the branch to assume a geniculated form like some of the ramifications of a Deer's horn, and no two appear to be exactly alike; in fact there is every appearance that each ray is influenced and modified in its development by the necessities of combination with the adjoining spicula, and their apices are directed in such a manner that they lap over each other in opposing lines, so that each two form a spliced joint, giving a much greater amount of strength than the mere crossing of the radii at various angles as in those of *Geodia*. The inhalant areas thus formed appear to differ very slightly from those of *Halichondria panicea*, in each of which several pores are opened, while those of *Dactylocalyx Prattii* seem to be devoted each to a smaller number (Plate XXIX. figs. 8 & 9).

As the ternate spicula thus united for the support of the dermal membrane would afford it little or no protection against the voracity of its smaller enemies, we find the necessary defence in innumerable short, stout, entirely spined cylindrical spicula not exceeding $\frac{1}{1000}$th of an inch in length; thus minute, there is no conceiving a predaceous creature with a mouth so small that they would not enter and become a subject of annoyance so great as to interfere seriously with its attacks on the membrane; and they are so numerous, and so closely packed together, that no portion of it equal in size to the length of a spiculum could be removed without one or two of them accompanying it.

A still further advance in this system of dermal support and defence is exhibited in the beautiful harrow tissue of Dr. A. Farre's siliceo-fibrous sponge, to which his specimen of *Euplectella cucumer*, Owen, is attached. In this case we have a perfect and regular quadrilateral network of smooth siliceous fibre, from the angles of which a double set of short conical spicular shafts are projected, each about $\frac{1}{150}$th of an inch in length and entirely spined. Each set are at right angles to the plane of the network, one series pointing inward, and serving the purposes of attachment to the mass of the sponge beneath, while the other set are directed outward, serving as defensive weapons; so that a small piece of this tissue beneath the microscope closely resembles an agricultural harrow, with the difference that it has two sets of teeth in opposite directions instead of one. The dermal membrane has been nearly all destroyed; but entangled with the fibres of the skeleton there are some attenuato-stellate spicula, with which it is probable the dermal membrane was amply furnished as secondary defences against its minute enemies.

I believe the surface presented to the eye in the portion represented in Plate XXXII. fig. 7 to be the external surface, as the fragments of the dermal membrane which remain all seem to cover that side of the fibres. Generally speaking there is some difficulty in detecting the double series of spicular organs at the angles of the network, but a reversal of the object beneath the microscope immediately removes all doubt on that subject.

In *Grantia compressa* and *ciliata* the intermarginal cavities appear to attain their highest degree of development, and are multiplied and expanded to such a degree as to almost supersede every other organ. The whole sponge in these species is formed of a great accumulation of elongated cells or cavities, closely adjoining each other and angular by compression. Their conical distal terminations, abounding in pores, represent the external surface of the sponge, while their valvular proximal ends form the inner surface, in conjunction with the shallow cavities, into the distal ends of which each cell discharges its contents. These shallow depressions, intervening between the intermarginal cavities and the cloaca, are all that remains to represent the incurrent portion of the interstitial systems so largely developed in the Halichondroid sponges, the great cloacal cavity entirely superseding the excurrent spaces and canals (Plate XXXIII. figs. 1 & 2).

In these species of *Grantia* there is no doubt regarding the existence of cilia, the whole of these great cavities being completely lined with them.

It is a question whether the intermarginal cavities share, in common with the interstitial canals, in the function of the assimilation of nutriment, or whether they are devoted solely to the aëration of the fluids of the animal; and this, if we consider the structure and extent of the interstitial canals in the Halichondroid sponges, is probably the case. In *Grantia* the abundant provision of cilia in those cavities at once stamps them as breathing-organs; and although cilia have never yet been satisfactorily proved to exist in the intermarginal cavities of the Halichondroid sponges, there can be no reasonable doubt of their being the homologues of the large ciliated cavities in *Grantia compressa* and other similarly constructed sponges. Now in these sponges, although the cilia may be readily seen in vivid action within the open oscula, as I have described at length in my paper "On the Ciliary Action of the Spongiadæ," published in the 'Transactions of the Microscopical Society of London,' vol. iii. p. 137, not the slightest trace of cilia exists without those organs; and this seems to indicate that the aërating functions were strictly confined in these sponges to the large intermarginal cavities.

The same mode of reasoning applies equally well to the intermarginal cavities of *Geodia* and *Pachymatisma*, to which it is probable that the cilia are in like manner confined. The great valves at the proximal ends of these cavities in this tribe of sponges appear to strongly indicate a decided separation of the functions of aëration and digestion; and if this conclusion be true in regard to the intermarginal cavities of *Geodia* and *Pachymatisma*, it will probably be so in the homologous organs in *Grantia*; and in this case we must look for the digestive surface in the shallow cavities intervening between the terminal valve of the intermarginal cavities and the parietes of the great cloaca, and of the surfaces of that organ itself. The structure and functions of the intermarginal cavities, and especially as displayed in *Geodia* and *Pachymatisma*, indicate a closer alliance with the great class Zoophyta than has hitherto been suspected to exist. In the one case we have an accumulation of individual animals conjoined in one mass; in the other a similar congregation of organs in place of individuals.

Dermal Membrane.

The dermal membrane envelopes the sponge entirely. When denuded of sarcode by partial decomposition, it has the appearance of a simple, pellucid, unorganized membrane. In the living state its inner surface is somewhat thickly coated with sarcode, and it has the appearance of, comparatively speaking, a stout, tough skin, and in many sponges it requires a considerable amount of violence to tear it. The dermal membrane of the Turkey sponge of commerce, *Spongia officinalis*, is abundantly supplied with primitive fibrous tissue. It curves round the margins of the porous areas, thickening and strengthening the whole of the dermis to a very considerable extent; but it exists to a very slight extent in the pellucid membranes of the areas in which the pores are opened. When alive, it is replete with powers of life and action of a very remarkable description.

Without the slightest appearance of nerves or muscles, it has the power of opening pores on any part of its surface and of closing them again at pleasure, without leaving a trace of their existence to indicate the spot they occupied; and there is no amount of laceration or destruction that it does not seem capable of repairing or replacing in a very short period, reproducing itself over extensively denuded surfaces in a very few hours. It also shares, in common with the interstitial membranes, the power of strongly and quickly adhering to other sponges of the same species with which it may be brought in contact, but never with those of a different species, however long the two may remain pressed against each other. In some sponges the distal extremities of the skeleton pass through and project beyond the surface of the dermal membrane, while in other cases the whole of the skeleton is confined within it.

I will not describe at length these remarkable powers of the dermal membrane, but refer the reader to a series of observations on the "Vital Powers of the Spongiadæ," published in the Reports of the British Association for 1856, p. 438, and for 1857, p. 121, in which I have described in detail a series of observations and experiments on living sponges, which demonstrate in a satisfactory manner the extent of the vital powers and capabilities of this highly sensitive membrane.

In some species of sponges the outer surface of the skeleton is especially modified to strengthen and support the dermal membrane. Thus in some of the keratose sponges of commerce, in parts of the sponge which have been in contact with other sponges, or with rocks or stones, we find a fine network of stout fibres immediately beneath the derma, as represented by fig. 9, Plate XXXII.; and *Isodictya varians*, Bowerbank, MS., is always furnished with a fine network of spicula, the reticulations consisting of a single series of spicula only, and on this framework the dermal membrane is firmly cemented. Fig. 8, Plate XXXII. represents a small portion of this dermal reticulation, magnified 108 linear.

In *Halichondria panicea* the same description of reticulation prevails, but in this sponge the fibres of the network are always composed of numerous spicula cemented together, as represented in fig. 5, Plate XXXII., illustrating the porous system of the above-named species of sponge. But this regularity of structure is not constant even in the same individual; thus in *Hal. panicea* you will often observe one portion of the dermis beautifully reticulated, while a closely adjoining spot will be supported by a series of matted spicula without any indication of areas for the pores, and these variations in structure are evidently determined by the presence or absence of those organs at particular parts of the surface. In other cases, beside a general attachment of the inner surface of the dermal membrane to the surface of the skeleton, we find it supported by numerous flat fasciculi of spicula dispersed irregularly on its inner surface, and differing materially in size and form from those of the skeleton, as in our common British species, *Halichondria incrustans*. Great variety exists in these modes of strengthening and supporting the dermal membrane; but those which I have described above will suffice to illustrate the general principles of their application. Beside the general systems of

external defence, the dermal membrane is often supplied with special defences. Thus in *Tethea muricata* (figs. 14 & 15, Plate XXXI.) we find its outer surface abundantly supplied with elongo-stellate spicula, which project externally to a considerable extent; and in *Dictyocylindrus stuposus*, Bowerbank, MS., beside the numerous defensive spicula projected through the surface, we find the membrane filled with minute sphero-stellate spicula, which would effectually protect it from the assaults of any minute enemies that might attempt to prey upon it. Fig. 6, Plate XXXII. represents a small portion of the dermal membrane of this sponge. This mode of defence is very general in the genera *Geodia*, *Tethea*, and *Pachymatisma*, and it occasionally occurs in many other genera of Spongiadæ.

The Pores.

The pores in the Spongiadæ are the orifices or mouths through which the animals breathe and imbibe their nutriment. They are situated in the dermal membrane, and are exceedingly numerous when the imbibing powers are in full operation. In *Pachymatisma* and *Geodia*, and in some other highly organized genera, there is good reason to believe that they are permanent organs, opening and closing repeatedly in the same situations. But in the greater part of the Halichondroid types of sponges they are certainly not permanent orifices like the mouths of higher classes of animals, and in these sponges, when they are in a state of complete repose, there is not the slightest indication of their existence. Their usual form is circular, but they frequently assume the shape of an elongated oval, and within a limited range they vary to a considerable extent in their dimensions; on the whole they exhibit a very constant and universal type of form and size; however different may be the internal structure of the sponges, or however great may be the difference in size of the individuals, they always appear to maintain their normal characters. No definite law appears to prevail in their distribution over the surface of the sponge, and they are liable to appear to a greater or a less extent on every part of its external surface, wherever there are intermarginal cavities beneath. The situations where they may be expected to appear may in many instances be readily recognized. Thus in *Halichondria panicea*, wherever we see on the dermal membrane a well-defined reticulation of spicula with clear and distinct areas, there, when the sponge is inhaling, we may expect to find the open pores, as represented in Plate XXXII., fig. 5, while on spots perhaps immediately adjoining, where the dermal membrane is occupied by a thickly interwoven mass, a felting of spicula, the probability is that not a single pore can be detected.

In some of the West India fistulose sponges we find the large or primary area of the dermal surface composed of keratose fibre, and within these large areas the dermal membrane is strengthened and supported by a secondary reticulation of spicula, in the areas of which the pores are opened. In these secondary reticulations the spicula are abundant, while in other parts of the sponge the tension spicula are rather of rare occurrence. In *Grantia*, a sponge of a widely different construction from those of the Halichondroid type, they occupy the distal extremities of the large intermarginal cavi-

ties of the sponge, and they appear to open over the whole of those portions of the cavities not in contact with the adjoining ones.

In *Pachymatisma Johnstonia*, a British sponge closely allied to the genus *Geodia*, we find the dermal membrane perforated by innumerable pores, some as minute as $\frac{1}{1000}$th of an inch in diameter, while others attain the size of $\frac{1}{150}$th of an inch. They are nearly equidistant from each other, but without any order in their arrangement. Immediately beneath the dermal membrane there is a stratum of membranous structure and sarcode destitute of gemmules, and about equal in thickness to one-third of that of the whole of the dermal crust, the remaining two-thirds of which consist of a stratum of gemmules or ovaries closely packed together, but perforated at intervals by the intermarginal cavities. Through the upper stratum, destitute of ovaries, a small canal passes from each pore to the nearest adjacent intermarginal cavity, so that there are a series of them at various angles, all concentrating their streams of inhaled fluid at the distal end of the cavity, which is gradually expanded in diameter to receive them. In these sponges therefore each mouth appears to be furnished with a separate œsophagus, if I may be allowed the term, connecting it with a stomach-like cavity common to a group of mouths above it—a system of organization strikingly in unison with that of the higher classes of animals. In some cases, as in *Geodia M^c^Andrewii* and *Barretti*, Bowerbank, MS., we find the pores systematically congregated in groups, as in Plate XXXII. fig. 4, which represents four groups from the latter species, and this congregation is accounted for by the peculiarities of the form and arrangement of the intermarginal cavities of that class of sponges.

The porous organs are still further complicated in a specimen of a branched sponge from the East Indies, presented to me by my friend Mr. S. P. Pratt. This sponge, which is a single branch about a foot in length and 9 lines greatest diameter, has nearly the whole of its surface abundantly furnished with peculiar and highly organized areas, as represented in Plate XXXV. fig. 3, each of which covers and protects a deeply depressed porous area, the depth of which in many cases rather exceeds its own diameter. The protective organ covering this depression is elaborately and beautifully constructed, very closely resembling, in many respects, the spiracula of *Dytiscus marginalis* and other similarly constructed insects. Each of the depressed areas of the sponge is furnished with ten semifollicular membranous cones, the whole of them being based on a common external marginal ring of dermal membrane, from which they are projected inward in the same plane as the dermal surface until their apices nearly meet in the centre of the inhalant area. The exterior surface of each cone is perfect and continuous from the marginal ring of membrane to its apex; but on the interior surface it is only perfect for about half its length from its apex backwards, as if half of the basal portion of a conical bag had been cut away from the remainder. Fig. 5, Plate XXXV. represents the exterior half of one of these protective organs, and fig. 6 the semifollicular structure of their conical organs. The membranes of which they are constructed are abundantly furnished with tension spicula, which are

dispersed without order on every part of their surface. It is the only instance I have seen of such an elaborate mode of protection of the porous areas in the Spongiadæ.

In my "Further Report on the Vitality of the Spongiadæ," published in the Reports of the British Association for 1857, I have described at length the opening and closing of the pores in *Spongilla fluviatilis*: each operation is commenced and terminated in less than a minute; they are perfectly dependent on the will of the animal; and in neither case are they simultaneous, but follow in irregular succession, in accordance with the necessities of the animal; and when once the pores are closed, they do not appear to ever open again in precisely the same spot.

In these wonderful opening and closing operations in the dermal membrane of *Spongilla*, every movement is accomplished as systematically and accurately as if there were a perfect system of nerves and muscles present, while not a vestige of fibrous structure can be detected in the thin translucent membrane and its sarcodous lining. No cicatrix remains for an instant after closing, no indication is perceived of the spot where the opening is the next moment to be effected.

In sponges exposed to the action of the atmosphere, between high and low water marks, and in dried specimens, the pores can rarely be detected. In the first case they are carefully closed on the receding of the tide, that the water within them may be safely retained during their exposure to the atmosphere; and in the latter case the violence offered to the sponge, and the shock of its removal from its native locality, are sufficient to induce an immediate closing of those organs, as I have shown in the details of my observations on these organs in *Spongilla* in the volume of the Reports of the British Association for 1857, to which I have before alluded. But should a specimen of marine sponge, after a careful removal from its place of growth, be placed in a shallow pan of sea-water, and be allowed to die of inanition, it then frequently expires with the whole or a considerable portion of the pores open, and in that state it may be readily preserved for the cabinet.

The Oscula.

The oscula are the fæcal orifices of the sponge. They are situated at the distal terminations of the single or concentrated excurrent canals of the animal. They vary considerably in form and size; sometimes they appear as single large orifices, while at others they consist of several small orifices grouped together. When the sponges are massive and solid, they are usually to be found dispersed over the dermal surface, but occasionally they are grouped on the highest portions or on the elevated ridges of the mass. In *Geodia Barretti* they are concentrated in deep depressions or pits. In other cases they are entirely hidden from view, lining the interior of elaborately constructed cloacæ situated in the centre of the sponge, as in *Grantia compressa* and *ciliata*, *Verongia fistulosa*, and a numerous series of species of fistulose sponges from the West Indies.

They are permanent organs, and are capable of being opened or closed at the will of the animal, and are subject to a considerable amount of variation in size and form, in

accordance with the variations in the actions of the sponge. Thus in littoral sponges they are frequently entirely closed, and their situation even quite indeterminable, during the period of their exposure to the air; but when immersed in water, and the sponge is in the energetic action of the imbibition of nutriment, they are expanded to their full extent; but when this action ceases and that of gentle respiration only exists, many of them close entirely, and others exhibit apertures not exceeding half their former diameter while the imbibition of nutriment was in vivid action. Their expansion or contraction is not rhythmical; each can be opened or closed at the will of the sponge without any apparent effect on the others. Nor is the habit of opening and closing the oscula the same in every species. Thus in the course of my observations on *Halichondria panicea* and *Hymeniacidon caruncula* in their natural and undisturbed localities, I have frequently observed, during their exposure to the air at low tide, that while no oscula in an open condition could be found in *Hymeniacidon caruncula*, the greater portion of those on the specimens of *Halichondria panicea* were more or less in an open state.

They appear also to be subject to a considerable amount of modification as regards situation, even in the same sponge. Thus in our common British species, *Halichondria panicea*, when of small size, they are situated on the surface of the sponge, and are scarcely, if at all, elevated above the dermal surface; while in large specimens of the same species we find them collected in the insides of large elongated tubular projections or common cloacæ, and these organs vary from a few lines only in height and diameter to tubular projections several inches in height, with an internal diameter of half or three-fourths of an inch. When they attain such dimensions their parietes are often of considerable thickness, and their external surface becomes an inhalant one, like that of the body of the sponge.

In many species the oscula are always elevated above the dermal surface, and these thin pellucid elevations are permanent, while in others, as in *Spongilla fluviatilis*, the tube exists only during the course of the energetic excurrent action; and in such cases it appears to be subject to great variation in size and form, as I have shown in the description of *Spongilla* in my "Further Report on the Vitality of the Spongiadæ," in the volume of the Reports of the British Association for 1857.

Inhalation and Exhalation.

The works of the old writers on Natural History are full of vague opinions on the nature of sponges, but none of them seem to have seriously studied their anatomy, or to have kept them alive in sea-water and examined their daily habits. They appear to have excited abundant attention in the closet, and but very little in their natural localities. The ideas of those authors are so loose and indefinite that it would really be a loss of time to seriously examine and attempt to refute them; and as Dr. JOHNSTON, in his 'History of British Sponges,' has given in his Introduction, Chapter 2, an excellent digest of the various opinions of the previous writers on the subject, I shall content myself with referring my readers to the work of that eminent author for further informa-

tion on these subjects, and with briefly referring to the few actual observations that appear to have been made by naturalists.

Marsigli, at the beginning of the 18th century, stated that he had seen contraction and dilatation in the oscula of several sponges just removed from the sea.

After Marsigli, Ellis (Ellis and Solander), Natural History of Zoophytes, pp. 184, 186, and 187 (see also Zool. Journ. pp. 375, 376), enunciated similar opinions founded on his own observations on the action of the oscula and their currents; but neither of those authors was aware of the true mode of the entrance of the water into the sponge, a much more difficult problem to solve than its exit through the oscula.

Cavolini in his researches, although made on sponges recently taken from the sea, failed in seeing the action of the oscula as Ellis had done, and he accordingly disputed the truth of those opinions. At a later period, Colonel Montagu, although actually examining sponges in the places of their growth, arrived at similar conclusions to those of Cavolini, and, like that author, he believed them to be animals of a very torpid nature. Montagu's reasoning to prove the animality of sponges is for the most part sound and excellent; he says, "Whether motion has ever been discovered or not in any species of sponge is not, I conceive, of so much importance as some naturalists would appear to consider. Those who are solicitous in their inquiries after the animals which they have supposed to construct the vesicular fabric of sponges, and have expressed their surprise that this in age of cultivated science no one should have discovered them, must have taken a very limited view of matter possessing vitality, and have grounded their hypothesis only upon supposed analogy." He also observes, "The true character of *Spongia* is that of a living, gelatinous flesh supported by innumerable cartilaginous or corneous fibres or spicula, most commonly ramified or reticulated, and furnished more or less with external pores or small mouths which absorb the water, and which is conveyed by an infinity of minute channels or capillary tubes through every part of the body, and is there decomposed and the oxygen absorbed as its principal nourishment, similar to the decomposition of air in the pulmonary organs of what are called perfect animals."—Wernerian Memoirs, vol. ii. pp. 74, 75.

Lamouroux's conclusions regarding the nature of sponges are so thoroughly vague and suppositious as scarcely to require notice.

Lamarck has placed the Spongiadæ in a higher position than any naturalist who had preceded him, giving them precedence of the sertularian and celliferous Corallines, and even of the Corallidæ; but I cannot concur with him to the full extent of his conclusions, which, like those of most previous writers, were derived to a much greater extent from comparative reasoning than from actual observation of the animals in a living and natural condition.

Professor Schweigger's opinions are very much more those of a practical naturalist, and it is evident that he had closely observed them in a living condition; but he too shares the erroneous opinion of his predecessors, that the oscula were the organs of imbibition, and that no water entered through the dermal surface. Professor Bell, in

the 'Zoological Journal' for June 1824, states that he saw the action of the streams from the oscula, but like previous writers concluded that they were organs of imbibition as well as excurrent organs. And it was not until the excellent and accurate "Observations and Experiments on the Structure and Functions of the Sponge" were published in the Edinburgh Philosophical Journal, vols. xiii. and xiv., by Professor GRANT, that a correct notion was entertained by naturalists of the inhalant and exhalant powers of those bodies. These details by the learned Professor are so full and complete as to leave but little room for the improvement of our knowledge of this portion of their natural history. And the facts of the imbibition of the surrounding water by the pores in the dermal membrane, its circulation through the internal cavities of the sponge, and its final ejection through the oscula, have been firmly established and acknowledged by all naturalists who have studied these animals closely in a living state. Dr. GRANT has, in truth, proved himself to have been, in regard to the aqueous circulation in the sponge, what HARVEY was to that of the blood of the higher classes of animal life, the first to discover and to publish the true mode of the circulation of the water in the animal.

This learned and accurate observer says, "I first placed a thin layer from the surface of the *S. papillaris* in a watch-glass with sea-water under the microscope, and on looking at its pores I perceived the floating particles driven with impetuosity through these openings; they floated with a gentle motion to the margin of the pores, rushed through with a greatly increased velocity, often striking on the gelatinous networks, and again relented their course when they had passed through the openings. The motions were exactly such as we should expect to be produced by cilia disposed round the inside of the pores."—Edinburgh New Philosophical Journal, vol. ii. p. 127.

The same author, in describing the excurrent action, says, "The *Spongia panicea* (*Halichondria incrustans*, JOHNSTON) presents the strongest current which I have yet seen." Two entire round portions of this sponge were placed together in a glass of sea-water with their orifices opposite to each other, at the distance of two inches; they appeared to the naked eye like two living batteries, and soon covered each other with feculent matter.

Stimulated by the recital of the observations of Dr. GRANT, I have often sought these currents flowing from the oscula, and there is no species which I have had the opportunity of examining in a fresh and vigorous condition in which I have not succeeded in seeing them. In the one observed by Dr. GRANT, *Halichondria incrustans*, JOHNSTON, the oscula being few in number and very large, the excurrent streams are more than usually powerful. In the course of my investigations "On the Vitality of the Spongiadæ," at Tenby, which are published in the Reports of the British Association for 1856, and in the "Further Report" published in the same work for 1857, I have described a long series of observations of the vital actions of the Spongiadæ as displayed in *Hymeniacidon caruncula* and *Spongilla fluviatilis*, in both of which species there was a perfect accordance in the habits and modes of exertion of these vital actions.

The power of inhalation appears to be exerted in the Spongiadæ in perfect accordance with the similar vital functions in the higher classes of animals, not involuntarily and

continuously as in the vegetable creation, but at intervals, and modified in the degree of its force by the instincts and necessities of the animal. And it may be readily seen that the faculty of inhalation is exercised in two distinct modes; one exceedingly vigorous, but of comparatively short duration, the other very gentle and persistent. In the exertion of the first mode of inhalation, that is during the feeding period, a vast number of pores are opened, and if the water be charged with a small portion of finely triturated indigo or carmine, the molecules of pigment are seen at some distance from the dermal membrane, at first slowly approaching it and gradually increasing their pace, until at last they seem to rush hastily into the open pores in every direction. In the meanwhile the oscula are widely open, and pouring out with considerable force each its stream of the excurrent fluid; and if the reflexion of one of the horizontal portions of a window-frame be brought immediately over an excurrent stream, it will frequently be seen that the surface of the water is considerably elevated by its action, even although the osculum be half or three-fourths of an inch beneath its surface, and this vigorous action will sometimes be continued for several hours, and then either gently subside or abruptly terminate. Occasionally a cessation of the action may be observed in some of the oscula while in others it is proceeding in its full vigour, and sometimes it will be suddenly renewed for a brief period in those in which it had apparently ceased. These vacillations in the performance of its functions are always indicative of an approaching cessation of its vigorous action. When the vivid expulsion of the water has ceased, the aspect of the oscula undergoes a considerable change; some of the smaller ones gradually close entirely, while in the larger ones their diameter is reduced to half or one-third of what it was while in full action. Simultaneously with the decline in the force of the excurrent action the greater portion of the pores are closed, a few only, dispersed over the surface of the sponge, remaining open to enable the gentle inhalation of the fluid to be continued, which is necessary for the aëration of the breathing surfaces of the sponge. The breathing state of inhalation appears to be very persistent, and I have rarely failed in detecting it when I have let a drop of water charged with molecules of indigo quietly sink through the clear fluid immediately above an open osculum. These alternations of repose and action are not dependent on mere mechanical causes, and sponges in a state of quiescence may be readily stimulated to vigorous action by placing them in fresh cool sea-water, and especially if it be poured somewhat roughly into the pan and agitated briskly for a short period; and this will take place even in specimens that have very recently been in powerful action.

No general law seems to guide the animal in the choice of its periods of action and repose, and no two sponges appear to coincide entirely in the time or mode of their actions. In fact, each appears to follow the promptings of its own instinct in the choice of its periods of feeding and repose.

In the littoral sponges there is a third condition of the animal, and that is during its exposure to the atmosphere in the intervals between high and low water, and in some sponges the pores and oscula are both completely closed. But this condition does not

obtain in all species. Thus, during the course of my investigations at Tenby, I observed that while, amidst the numerous specimens of *Hymeniacidon caruncula* and *Halichondria panicea* that covered the rocks in the neighbourhood of St. Catherine's Cave, the former rarely exhibited an open osculum in the absence of the water, those of the latter species were frequently more or less open.

The most beautiful and striking view of the differences existing between vigorous action and the comparative repose of the breathing process is exhibited in *Grantia ciliata*. In this species the pores are situated on the obtusely conical distal terminations of the intermarginal cells or cavities, each of which is furnished with a long fringe of spicula surrounding its porous end, their proximal terminations being cemented, for about a third of their length, to the slightly curved surface of the base of the cone. In the state of the comparative repose of aërating inhalation, and when the base of the conical extremity of the cavity is not distended by the incurrent action, these spicula all converge to a point at the level of their own apices, and the water thus gently inhaled passes between the shafts of the spicula, forming the protective cone to the inhalant pores, and effectually preventing any extraneous matter from approaching them. But when the vigorous feeding action commences, the distention of the base of the conical portion of the cavity brings it into lines parallel to the axis of the cell, and thus the conical fringe of spicula assumes a cylindrical form, and the molecular food of the animal is freely admitted to the pores.

A corresponding action obtains in the exhalant system of this interesting sponge. The mouth of the great central cloaca is furnished with a thick fringe of very long and slender spicula, which by the contraction of its sides near the mouth are all brought to assume a conical form like those appended to the inhalant cavities; but when the inhalant action is in vigorous operation, and the oscula are all pouring their streams into the cloaca, the force of the water thus accumulated distends the mouth of the cloaca to such an extent as to cause the fringe of long spicula to assume the form of an open cylinder, or in some cases it is expanded to such an extent as to become slightly funnel-shaped, and in this condition the fæcal stream may be seen issuing from it with considerable force. There are many other interesting points in the structure of this highly organized and interesting sponge which I will not advert to at length, but refer my reader to a fuller and more complete history of its structure published by me in the 'Transactions of the Microscopical Society of London' for 1859, vol. vii. p. 79, plate 5.

Thus we find that inhalation is the primary vital operation induced by ciliary action, and that exhalation is merely a mechanical effect arising from the primary cause. We find also that these actions are separated into two distinct modes; the one exceedingly active and vigorous, exerted only at intervals and for short periods, and the other gentle and continuous. If we combine the consideration of these peculiarities of function with those of the anatomical studies, we find that the incurrent streams are always received in intermarginal cavities, and that these organs, however modified, are always present, and in some cases can be distinctly and strikingly separated from the great mass of the

interstitial canals and cavities of the sponge. If we trace the course of the inhaled fluids, we find that on their entrance through the pores they are first brought into contact with the parietes of the intermarginal cavities, and passed thence into the complicated system of digestive surfaces which line the incurrent and excurrent canals and cavities of the sponge, and that the exhausted fluids charged with fæcal matters are finally discharged without the slightest return to or intermixture with the contents of the intermarginal cavities. We may therefore, it appears to me, safely conclude that the respiratory and digestive functions are separated, and that the latter has its seat in the intermarginal cavities, and the former in the interstitial canals and cavities.

The vital energy of the Spongiadæ must be very considerable, and the quantity of oxygen consumed by their respiration great, if we may judge by the effects of their presence in the vivarium, where their introduction makes sad havoc among the other inhabitants, few being able to withstand their deleterious presence, and without a large supply of water and a frequent change of it they themselves quickly expire of exhaustion.

Nutrition.

In treating on the subjects of inhalation and exhalation, I have described the energetic period of action in the sponge during the imbibition of the surrounding fluid as equivalent to the operation of feeding in the higher classes of animals. And in my "Further Report on the Vitality of the Spongiadæ," published in the Reports of the British Association for 1857, p. 121, I have described the results of feeding a small specimen of *Spongilla fluviatilis* with finely comminuted indigo in water, and I have there stated that "many of the molecules might be readily followed, as they meandered through the interior of the sponge, and were seen flowing in every direction. During the maintenance of this action in full force, when I directed my observation to the osculum, it was pouring forth a continuous stream of water, and along with it masses of flocculent matter, and many of the larger molecules of the indigo that had entered by the pores; but it is remarkable that although the finer molecules of indigo were being imbibed by the pores in very considerable numbers, very few indeed of them were ejected from the osculum; and if the imbibition of the molecules continue for half an hour or an hour, and then cease, the sponge is seen to be very strongly tinted with the blue colour of the indigo, and it remains so for 12 or 18 hours, after which period it resumes its pellucid appearance, the whole of the imbibed molecules having undergone digestion in the sarcode lining the interior of the sponge, and the effete matter having been ejected through the osculum." If we kill the sponge immediately after being thus fed, and examine the interstitial canals and cavities, we find their sarcodous surfaces thickly dotted with molecules of indigo.

The fæcal matters discharged by the oscula exhibit all the characteristics of having undergone a complete digestion; whatever may have been the condition of molecules of organized matter when they entered the sponge, their appearance after their ejection is always that of a state of thorough exhaustion and collapse.

It is difficult to decide with any degree of certainty what is really the nature of the nutriment of the Spongiadæ, but in the greater number of species it is probably molecules of both animal and vegetable bodies, either living or derived from decomposition. This appears to be the case with the greater number of the Halichondroid sponges; but even among them, as well as other genera, there are peculiarities of structure that are strongly suggestive of carnivorous habits. Thus, in the first portion of this paper published in the 'Philosophical Transactions' for 1858, p. 293, I have described among the interior defensive spicula a remarkable form, which has been hitherto found in one sponge only, the spinulo-recurvo-quaternate spiculum, which "occurs in great profusion in the cavities of the sponge; clusters of them, consisting frequently of as many as twelve or fifteen, radiate from the angles of the reticulations of the skeleton into the interstitial cavities of the animal." I have also described, while treating on the internal defensive spicula, the recurvo-ternate forms, the heads of which are found projecting their radii, more or less, into the interstitial cavities beneath the intermarginal ones in *Geodia* and *Pachymatisma*. The spinulo-recurvo-quaternate spicula, represented *in situ* in Plate XXX. fig. 10, and the recurvo-ternate ones, figured *in situ* in Plate XXXII. fig. 2, *e*, *e*, *e*, are both admirably adapted to destroy the victims entangled among them.

I have for a long time entertained the idea that these elaborate and varied forms of defensive spicula probably subserved other purposes than that of the protection of the digestive surface against the incursions of minute annelids and other predaceous creatures. They are admirably fitted to retain and make prey of any such intruders. No small animal could become entangled in the sinuosities of the interstitial cavities of sponges thus armed without extreme injury from the numerous points of these spicula, and every contortion arising from its struggles to escape from its painful and dangerous entanglement would contribute to its destruction, and it may then, by its death and decomposition, eventually become as instrumental to the sustentation of the sponge as if actually swallowed by the animal. How far this mode of nutrimentation may obtain in the physiology of these creatures it is impossible, in the present imperfect state of our knowledge of their habits to say; but, from the complex, varied, and elaborate structure of these organs, and from their evident adaptation to retain such intruders, as well as to defend the internal surfaces from injury, it is not improbable that their office extends beyond that of the mere defensive function, and that they are, in fact, auxiliary organs for securing nutriment for the use of the sponge. If this supposition, that the elaborately formed and ingeniously disposed recurvo-quaternate spicula combine the office of securing prey with that of defending the interstitial organs of the sponge, be correct, it may afford a clue to the organic purpose of the recurvo-ternate spicula with the exceedingly long and attenuated shafts that so frequently accompany the stout patento-ternate ones in *Geodia Barretti*. The apices of these spicula (Plate XXIII. fig. 45, Phil. Trans. for 1858) rarely attain the height of the plane of the true connecting spicula, and their recurved radii are most frequently projected into the large interstitial spaces immediately beneath the plane of the proximal ends of the cells of the intermarginal

cavities, and may thus form subsidiary defences to those organs. Although emanating from the fasciculi of the shafts of the true connecting spicula, their form, slender proportion and position evidently indicate a different office from the spicula with which they are associated, and no other purpose for them occurs to me so probable as the one I have suggested above. Or we may carry the supposition further, and believe them to be not only defensive but aggressive organs; also, like the recurvo-quaternate spicula, their office may be to retain soft annelids that have intruded themselves through the oscula into the digestive organs, to aid in the nutrimentation of the sponge; and this idea appears the more admissible as these spicula are never observed in the intermarginal cavities, where the decomposition of animal matters would be offensive to their especial function, but always in the spaces beneath them, which are the commencements of the digestive system.

The same course of reasoning will apply to their occurrence in such considerable quantities amidst the defensive fasciculi of spicula projected from the surface of *Tethea simillimus*, and also of *T. crania*, the latter being represented in Plate XXIX. fig. 12 *c*, in which it will be seen that the recurvo-ternate heads of the spicula are always situated beneath the level of the true defensive spicula. Thus situated they would form an admirable trap for the entanglement of soft annelids that might attempt to crawl over the surface of the sponge, and thus they would be destroyed and retained for the imbibition of their particles liberated by their gradual decomposition. If this be not their especial purpose in this situation, I must confess myself at a loss to imagine their proper function, as the surface of the sponge is effectually protected by the porrecto-ternate and large acute spicula that compose the defensive fasciculi projecting in such abundance from all parts of the sponge. If we also consider the structure and positions of the ordinary forms of internal defensive spicula, the entirely spined attenuato-acuate ones, in reference to the idea of their being offensive as well as defensive organs, we shall not fail to see that, although less striking in their forms and modes of disposition than the spicula already described, they are calculated to subserve the office of retaining prey quite as effectually as the more singular ones. The abundance in which they occur, the vast number of spines with which they are covered, the apices of which are frequently long and recurved, combined with the mode in which their bases are attached to the fibres of the skeleton, exhibiting a beautiful combination of strength and flexibility, are strongly indicative of a purpose beyond that of mere repulsion.

In the two species of sponges in which are found the acuate entirely and verticillately spined defensive spicula *in situ*, represented in Plate XXX. figs. 7 & 8, one of them has the spicula collected in groups in a manner very similar to those of the spinulo-recurvo-quaternate form, and if the latter be considered as organs for the retention of prey, the physiological purpose of the grouping together of the former can scarcely be considered in any other light.

In the isolated positions of these forms of spicula, viewed in reference to some ideas regarding their physiological purposes, there are some circumstances of a very remark-

able nature. These forms of spicula occur in several distinct genera of sponges, and especially in those having a strong kerato-fibrous skeleton. Their usual locality is on the fibre of the skeleton, in which their bases are firmly imbedded, and from which they are projected at various angles into the canals and cavities of the sponge, and they are very rarely seen on the membranes. In *Hymeraphia stellifera* (Plate XXX. fig. 3, *a*) and *clavata*, Bowerbank, MS., both exceedingly thin coating species, they occur in great quantity, but only on the basal membrane; a portion of them being erect, the remainder prostrate. But in another sponge, a remarkably curious parasitical species of *Hymeniacidon*, which, having no fibrous skeleton of its own, covers and appropriates a small fibrous *Fucus*, and converts its anastomosing vegetable stalks into an artificial skeleton, closely coating each stalk of the plant with its membranous structure, so as to cause them at first sight to be readily mistaken for keratose sponge fibre, the whole of the membranous structure abounds with attenuato-cylindrical entirely spined defensive spicula; but they are all prostrate and intermingled with the skeleton spicula of the sponge when not in contact with any part of the fibres of the vegetable, but wherever they are in contact with the plant they instinctively, as it were, assume the erect position, and the false skeleton is bristling with them to as great an extent as if it were truly a keratose fibrous structure. This feature in the habit of the sponge is very remarkable, and highly suggestive of a capability of adaptation to circumstances that we should scarcely have expected to find. By the two instinctive habits, first, that of converting the plant into an artificial skeleton, and then erecting its spinous spicula on its fibres, it at once simulates the habits of a kerato-fibrous sponge, and becomes capable of the carnivorous habits that I have attributed to those sponges that are so strikingly adapted for preying on intruding annelids or other such small creatures. In the species above described, *Hymeniacidon Cliftoni*, Bowerbank, MS., Plate XXX. fig. 9, the erection of the spicula on the adopted skeleton is an established habit, and it may be said to be instinctive in the species, but I have observed the same fact in sponges not habitually parasitical. I have a specimen of *Microciona carnosa*, Bowerbank, MS., a British species, in my possession in which some small fibres of a tubular zoophyte have been accidentally included during its growth, which the sponge has coated with its own tissues, and from these adopted columns defensive spicula are projected in a similar manner to those of the columnar skeleton of the sponge. In this case we have an instinctive adaptation of an extraneous substance in a sponge in which the introduction of foreign substances is the exception, and not, as in other tribes of sponges, the rule.

In *Hyalonema mirabilis*, Gray, a sponge nearly related to the genus *Alcyoncellum*, we find another extraordinary series of internal defensive spicula, the structure of which I have described at length under the head of 'Defensive Organs.' These elaborately and wonderfully formed weapons are evidently destined for other purposes than that of simple repulsion. The spiculated cruciform spicula, with their short stout basal radii planted firmly on the lines of the skeleton, and projecting from their centre at right angles to their own plane, the long spiculated ray furnished with numerous strong sharp

recurved spines, it will be at once seen, are eminently fitted to retain annelids or other such prey, and to cause every motion of the struggling victim to contribute to its own laceration and destruction, while the structure and mode of attachment of the cruciform base is admirably calculated to resist the force and motions it has to sustain in such encounters. But these spicula, although exceedingly numerous, are not the only organs capable of retaining intruders into the body of the sponge with which it is furnished: there are, in addition, numerous large multihamate birotulate spicula dispersed in various positions on the sides of the interstitial cavities of the sponge, each of the rotulæ consisting of seven or eight stout recurved flattened radii, which if immersed in any struggling animal would be capable of sustaining a vastly greater amount of force than many of the spiculated quadriradiate ones combined could endure without injury; and that their especial office is that of auxiliary retentive organs is well demonstrated by the fact that the trenchant edges of the flattened radii are all at right angles to the line of force required to tear away their hold of any body in which they may have been inserted. Thus they appear destined by nature to secure the prey, while its own struggles among the lacerating organs contribute to its destruction (Plate XXXI. figs. 3, 4, 5, 6 & 7).

In the modification of the structure of the contort bihamate spicula, and their peculiar adaptation to the retention and destruction of intruders within the sponge, which I have described when treating on the internal defensive spicula, and which is represented in Plate XXXI. figs. 1 & 2, we have precisely the same physiological principle carried out, but by means widely different from those I have previously described.

If we consider the whole of these extraordinary organs to which I have referred in relation to each other, we cannot fail to see that, however varied their forms may be, there is every appearance of perfect harmony of design in the purposes they are destined to effect in the economy of the Spongiadæ.

The Cilia and Ciliary Action.

Our knowledge of the cilia of the Spongiadæ is, comparatively speaking, very small. Dr. Grant is, I believe, the first author who has seen and described these organs *in situ*. This learned and accurate observer, in his paper "Observations on the Structure and Functions of the Sponge," has described the origin and gradual development of the ova or gemmules of *Spongia panicea* (*Halichondria incrustans*, Johnston). After the liberation of these bodies from the sponge, he writes, "The most remarkable appearance exhibited by these ova is their continuing to swim about, by their own spontaneous motions, for two or three days after their detachment from the parent, when they are placed separately in vessels of sea-water, at perfect rest. During their progressive motions they always carry their rounded broad extremity forward, and when we examine them under a powerful microscope we perceive that these motions are produced by the rapid vibration of cilia, which completely cover over the anterior two-thirds of their surface." And he further states that they are "longest and exhibit the most distinct motions on the anterior part," and that they "are very minute transparent filaments, broadest at their

base, and tapering to invisible points at their free extremities; they have no perceptible order of succession in their motions, nor are they synchronous, but strike the water by constantly and rapidly extending and inflecting themselves." The author describes the attachment and spreading out into a thin disk of the ovum or gemmule, and the cessation of action and gradual disappearance of the cilia; and he further observes, "although all visible cilia have ceased to move, we still perceive a clear space round the ovum, and a halo of accumulated sediment at a little distance from the margin." This observation is important, as tending to prove the existence of ciliary action, although the organs themselves were too minute to be detected.

Dujardin, in his work on the Infusoria, in plate 3, fig. 19 *b*, represents what are apparently the detached cilia and their basal cells, and which were probably from *Grantia compressa*.

If portions of a living sponge of this species be torn into small pieces, and placed in a cell in sea-water under a power of about 400 linear, groups of the detached cilia and their basal cells will be readily seen at the margins of the specimen; they are usually thus clustered together, and have a tremulous and indistinct motion. If a small specimen of the sponge be slit open and placed in a cell with fresh sea-water, with the inner surface of the sponge towards the eye so as to command a distinct view of the oscula, the cilia will be seen in the area of that organ in rapid motion, and the extraneous molecules attached to them exhibit the extent and nature of their oscillations very distinctly (Plate XXXIII. fig. 2). If the sponge be carefully torn asunder in a line at right angles to its long axis, and the torn surface be placed in a cell with a little fresh sea-water, we occasionally obtain a favourable longitudinal section of some of the large cells of the sponge, and we then see the cilia *in situ* and in motion (Plate XXXIII. fig. 1).

The whole length of the cell, from the inner edge of the diaphragm to its origin near the outer surface of the sponge, is covered with tessellated nucleated cells, which have each a long attenuated and very slender cilium at its outer end. They are oval in form, and have a distinct nucleus. When in vigorous condition their motions are rapid and cannot readily be followed; but in some in which the action was languid, the upper portion of the cilium was thrown gently backward towards the surface of the sponge, and then lashed briskly forward towards the osculum, and this action was steadily and regularly repeated. Their motions are not synchronous—each evidently acts independently of the others (Plate XXXIII. fig. 3, *a* & *b*).

The numbers, situation, and peculiarities of their actions fully account for the continuous and powerful stream that issues from the great cloacal aperture of this and other similarly constructed sponges. The natural rate of the motions of these organs must not be estimated from the sections last described, but the estimate must be made from the appearances manifested at the oscular orifices at the inner surface of the sponge. A more detailed account of these investigations is published in the Transactions of the Microscopical Society of London, vol. iii. p. 137. Figs. 1, 2, 3, & 4, plate 7, represent

a longitudinal section of the intermarginal cavities of *Grantia compressa* with the cilia *in situ*. A view of the small portion of the inner surface of the sponge, exhibiting the oscular orifices and the appearance of the cilia in motion within them, and detached cilia and cells from the same sponge, are also represented by figs. 1, 2, 3 & 4, Plate XXXIII.

In the course of my endeavours to detect the cilia in Halichondroid sponges, I have frequently observed, in slices of the sponge taken from the surface, that the incurrent action has continued for a considerable period, while in sections of the same sponge taken from deep amid the tissues no such action of the currents could be detected. In sections from the surface in which the inhaling process was in vigorous condition, when the inside of the section was examined, that peculiar flickering appearance was often visible in the cavities immediately beneath the dermal membrane which is so characteristic of minute cilia in very rapid motion; and although many molecules were rushing inward with considerable velocity, others might be seen which continually waved from side to side but made no progress forward; in fact they presented precisely the appearance that I have described as taking place in the oscula of the proximal ends of the great intermarginal cells of *Grantia compressa*; and I have no doubt, in my own mind, that those of the Halichondroid sponges were also extraneous particles of matter adhering to the apices of the minute cilia, rendering their motions apparent, while the cilia themselves were perfectly invisible.

Carter, in his paper on "Zoosperms in *Spongilla*," published in the 'Annals and Mag. Nat. Hist.' vol. xiv. Second Series, p. 334, describes ciliated bodies from a *Spongilla* from the water-tanks of Bombay, somewhat similar to those of *Grantia compressa*, but the basal cell appears to be proportionally larger and the cilium shorter than in those of *G. compressa*. The author, in describing the detached cells and cilia, says, "At first the polymorphism of the cell and movements of the tail are so rapid, that, literally, neither 'head nor tail' can be made out of the little mass. Presently, however, its power of progression and motion begins to fail, and if separated from other fragments it soon becomes stationary, and after a little polymorphism assumes its natural passive form, which is that of a spherical cell. During this time the motions of the tail become more and more languid, and at length cease altogether." The author continues, "If, on the other hand, there be very large fragments in the immediate neighbourhood, or an active sponge-cell under polymorphism sweeps over the field, it may attach itself to one or the other of these, when its cell becomes undistinguishable from the common mass, and the tail floating and undulating outwards is all that remains visible." This observation is important, as it accounts in a great measure for our inability to find the cilia *in situ* in the living and active condition of the *Spongilla*; and if the structure and imbedment of the basal cell in the marine sponges be like those in that genus, the same results would probably arise in the marine species, rendering it extremely difficult, if not impossible, to detect these organs *in situ* and in action.

Lieberkuhn, in his paper in Müller's 'Archiv,' 1856, pp. 1–19, 319–414, gives an

account of the cilia and their cells *in situ*. He describes them as forming a single layer of spherical cells, $\frac{1}{300}$ millim. in diameter, and which, though touching each other, are not in such contact as to lose their rounded figure. LIEBERKUHN'S description of the mode of disposition of these cells in *Spongilla* would serve equally well for those in *Grantia compressa*. Professor HUXLEY, in a paper "On the Anatomy of the Genus *Tethya*," published in the 'Annals and Mag. Nat. Hist.' vol. vii. p. 370, describes cells and cilia from an Australian sponge, which he designates spermatozoa, and which he describes as having "long, pointed, somewhat triangular heads, about $\frac{1}{100}$th of an inch in diameter, with truncated bases, from which a very long filiform tail proceeds." These bodies are figured in vol. vii. plate 14. fig. 9.

On a careful consideration of the descriptions of the ciliated cells seen by the authors I have quoted above, it strikes me forcibly that the so-called zoosperms and spermatozoa of CARTER and HUXLEY are identical in origin and purpose with the similar organs described by LIEBERKUHN and those found *in situ* and in action in *Grantia compressa*, and, in truth, that they are the homologues of the breathing and feeding organs of the zoophytes and more highly organized animals.

Reproduction.

The ovaria in sponges exhibit considerable variety in shape and structure. The most familiar form is that of *Spongilla fluviatilis*, represented in Plate XXXIII. fig. 5, in its natural condition.

These bodies have hitherto been usually designated as gemmules, but this term appears to be inappropriate. Each of them contains numerous minute vesicular, round or oval molecules, which are discharged from the foramen in succession, and each of these appears to be capable of producing a sponge. The terms ovarium and ova are therefore more in accordance with the rules of modern nomenclature, and this alteration in their designation is the more necessary, as I shall hereafter be enabled to show that, at least in *Tethea lyncurium*, propagation by true external gemmation really exists. I propose, therefore, for the future that all such large vesicular organs containing numerous molecules or ova capable of reproducing the species, and of being successively ejected from the sponge, should be designated ovaria and ova, and that the term gemmule should be restricted to the isolated bodies which pullulate from the internal or external surfaces of the parent, and by ultimate separation become each a distinct individual.

The reproductive powers of the Spongiadæ have been treated of to a considerable extent by preceding authors, and the amount of our information on this subject is, I believe, both extensive and accurate. I will not attempt a recapitulation of all that has been written on their reproduction, but content myself with a slight sketch of our knowledge of the various modes of propagation that have been well ascertained and described. From the researches of the various authors who have written on the structure and development of *Spongilla* and on the marine Spongiadæ, it appears that there are three well-

established modes of propagation: 1st, by ova; 2nd, by gemmation; and 3rd, by spontaneous division of the sarcode. The terms ova and gemmule have been used so indiscriminately by authors, that it seems to me advisable to endeavour to define and limit their application in such a manner as to distinctly separate the one form of reproductive body from the other.

On a careful review of the results of the labours of previous observers and of my own researches, it appears that the following may be considered as the varieties that exist in the modes of the propagation of the Spongiadæ:—

1st. By ova without an ovarium.
2nd. By ova generated within ovaria.
3rd. By gemmules secreted within the sponge.
4th. By gemmules produced externally.
5th. By spontaneous division of the sarcode.

On the first mode of propagation, by the means of ova generated in the sponge without the presence of ovaria, very little seems to be known; and this mode appears to be confined to the true sponges, the genus *Spongia*. If we examine microscopically the fibres of the sponges of commerce in the condition in which they come into the hands of the dealers, and before they have been soaked, cleaned, and prepared for sale, we frequently find the fibres covered with innumerable minute irregularly ovoid vesicular bodies, nearly uniform in size, dispersed evenly over the surface of the fibres, and imbedded in a thin stratum of sarcode that coats the membranous sheath that surrounds them. These bodies Dr. Johnston believes to be "the matured gemmules or sporules," and I feel strongly inclined to agree with him in the conclusion that they are the reproductive bodies of that tribe of sponges, and no other reproductive bodies have, I believe, been discovered in the true sponges; but in arriving at this conclusion we must not fail to remember that our knowledge of these animals in the fleshy and solid condition in which they are when alive is so limited, and so few observations have been published regarding them in that state, that we must not attach too great a value to these conclusions.

In size and form these ovoid vesicles are very similar to the ova liberated from the well-characterized ovaria of other marine species of Spongiadæ, and, like them, they present no appearance of a nucleus. They are somewhat irregular in their form, and vary to a slight extent in size; an average-sized one measured $\frac{1}{1166}$th of an inch in diameter. Fig. 6, Plate XXXIII. represents a portion of a fibre from a Bahama sponge under a power of 400 linear, and fig. 7 a part of the same fibre $\times 1250$ linear.

Until very recently, our knowledge of the vesicular ovaria of the Spongilladæ has been confined to two European species; but Carter, in his excellent account of the Spongillas found in the water-tanks of Bombay, has described several new and interesting varieties of these organs; and I have also become acquainted with eight new species from the River Amazon, through the kindness of Mr. Bate, and of three undescribed species from North America, through the kind and liberal assistance of Dr. Asa Gray,

Professor Leidey, and Professor Dawson, of M^{c}Gill College, Montreal, Canada. The greater portion of these organs resemble each other very closely in their natural condition, presenting generally the appearance of a more or less spherical coriaceous body; but the structure of their walls, when developed by treating them carefully with hot nitric acid, is so varied and strikingly characteristic of their organic and specific differences, as to render it necessary that I should enter somewhat minutely into their history. Their structual peculiarities naturally divide them into two great groups.

1st, those in which the walls of the ovaria are strengthened and supported by birotulate or unirotulate spicula radiating in lines from the centre to the circumference of the ovarium; and 2nd, those having the walls of the ovaria supported by elongate forms of spicula, disposed on or near its surface at right angles to lines radiating from the centre to the circumference of the ovarium; and, fortunately, the types of these two forms of spicular arrangement on the cortex of the ovarium are admirably illustrated in the two European species of *Spongilla*, the first mode existing in *Spongilla fluviatilis*, and the second one in *S. lacustris*. After having described the ovaria of these two species as types of their respective groups, I shall, in my future descriptions of these organs, confine my observations rather to their anatomical structure than to their external characters, excepting when the latter are of an unusual description. These bodies occur in great profusion in the basal portions of *S. fluviatilis*; they are spherical and of an average diameter of $\frac{1}{60}$th of an inch, and they are furnished with a circular foramen at their distal extremity of about $\frac{1}{833}$rd of an inch in diameter. In their natural condition they exhibit very slight indications of the birotulate spicula imbedded in their coriaceous-looking envelope. In the dried state they become cup-shaped by the contraction of the upper half inward during the process of desiccation, and in this condition the foramen appears at the bottom of the cup. The edges of the cup being thick and round in consequence of the presence of the birotulate spicula beneath the fold of the membrane, the surface becomes pitted with numerous minute lacunæ, which are produced by the adhesion of the inner surface of the envelope to the distal extremities of the birotulate spicula. Immersion in water for an hour restores them to their spherical form, but does not obliterate the lacunæ produced by desiccation; and I have several times observed that, under these circumstances, the expansion of the ova within has forced one or more of them through the foramen.

If we take several of the ovaria, either in the living condition or in the expanded state I have described above, and place them in a test-tube with a little nitric acid, and raise the temperature of the whole until the ovaria become of a bright yellow colour and semitransparent, and then arrest the operation of the acid by immediately pouring in a quantity of cold water, we shall have preserved their form and have retained the spicula in their natural positions, and have rendered the whole so transparent, as to exhibit their form and arrangement in the walls of the ovarium, either in water or mounted in Canada balsam, in a very beautiful and satisfactory manner. They are packed very closely together, their shafts being in lines radiating from the centre of the

ovarium to the circumference; their distal rotulæ supporting the outer surface of its wall, while the proximal rotulæ sustain the inner one. Fig. 8, Plate XXXIII. represents a portion of one of these prepared ovaria, and fig. 8 *a* one of the detached spicula. Two views of this form of spiculum are also represented in Plate XXVI. figs. 27 & 28, Phil. Trans. 1858, and a perfect ovarium prepared by acid by fig. 9, Plate XXXIII.

Carter, in his paper "On the Freshwater Sponges in the Island of Bombay," in describing the birotulate spicula of the ovaria of *Spongilla Meyeni* and *plumosa*, species with ovaries of very similar structure to those of *S. fluviatilis*, states that the spaces between the rotulæ are "filled up with a white siliceous amorphous matter, which keeps them in position." I am indebted to the kindness and liberality of the author for specimens of these species, and I have frequently subjected their ovaries to the action of hot nitric acid, but I have never succeeded in finding any intervening siliceous matter, nor have I ever found any such siliceous cementing material in any other similarly constructed ovary of a *Spongilla*.

In the second group of ovaries of the Spongilladæ, represented by those of *S. lacustris*, in which the walls of the ovarium are supported by elongate forms of spicula disposed at right angles to lines radiating from its centre, the ovaria, in their natural condition, exhibit but very slight traces of the spicula imbedded in their walls. When dried, they cup inward like those of *S. lacustris*; but the margin of the cup is thin and sharp compared with that formed in a similar manner by those of *S. fluviatilis*, and they expand also in like manner when immersed in water. When treated with hot nitric acid they display an abundance of short, stout, entirely spined, subarcuate acerate spicula, one of which is represented in Plate XXVI. fig. 13, Phil. Trans. 1858. These spicula are in many instances exceedingly numerous; they are disposed without order, and overlie each other at various angles, forming, in their imbedment in the envelope, a strong and very efficient irregular network of spicula. A portion of one of these prepared ovaria is represented in Plate XXXIII. fig. 10.

In the ovaries of the different species of *Spongilla*, to be arranged hereafter in accordance with their structural peculiarities, there is a considerable amount of general resemblance, but accompanied with such permanent variations in the structure of the spicula, and in other portions of the development of these organs, as to render a somewhat detailed description of them necessary. Thus, in the development of the birotulate spicula, the ovaries of *Spongilla plumosa*, Carter, exceed any other known species. The thick walls of these organs are filled with them in the state represented by fig. 21, Plate XXVI. Phil. Trans. 1858, and the intervals between their shafts appear to be filled with indurated sarcode or keratode. In *Spongilla Meyeni*, Carter, the walls of the ovaria are strikingly similar in their structure to those of *S. fluviatilis*, and the form of the spicula the same, with the exception of the shafts being very much more spinous, and the size of the spiculum twice that of *S. fluviatilis*. Fig. 29, Plate XXVI. Phil. Trans. 1858, represents a spiculum from an ovary of *S. Meyeni*. The smallest and most simple development of birotulate spicula exists in *Spongilla gregaria*, Bowerbank,

MS., from the River Amazon, represented by figs. 23, 24, 25 & 26, Plate XXVI. Phil. Trans. 1858.

A gradual transition from the birotulate form to that of the unirotulate one takes place in the ovaries of *S. paulula* (fig. 31) and *S. reticulata* (fig. 33), until we obtain the perfect and beautiful unirotulate form in the ovaries of *S. recurvata*, represented by figs. 34 & 35 in the Plate quoted above. In all these species there is a general accordance in the mode of their structure.

The gradual transition from the birotulate to the unirotulate form of spiculum in the ovaries of *Spongilla reticulata* is not the only characteristic difference that exists between it and its congener. The form and structure of the ovarium also exhibit marked peculiarities of character, and it is also furnished with a beautiful reticulated spicular envelope or case. In its natural condition the ovary fills the reticulated case, and the coriaceous external surface is pressed into the areas of the network.

It is usually oviform, but it varies to some extent in its shape. When treated carefully with hot nitric acid, the outer coriaceous substance of the ovarium is dissolved, leaving the inner membrane and the boletiform spicula *in situ*; their larger terminations being applied to the distal surface of the membrane, while their smaller clavate or stellate ends are projected outward, reaching, in the natural condition, to very near the external surface of the ovarium. The foramen is situated at the small or distal end of the ovary, and differs from that of any other form of the organ with which I am acquainted, inasmuch as it exhibits a tubular elongation outward of the lining membrane equal in length to about its own diameter, causing the ovarium, when prepared with nitric acid, to appear like an oil-flask with a very short neck. Fig. 13, Plate XXXIII. represents one of the ovaria prepared with acid, and fig. 12 one of the cases in which they are contained.

In *Spongilla Brownii*, Bowerbank, MS., there is a still further deviation in the structure of the spicula of the ovary. The shaft entirely disappears, and the spiculum is reduced to the umbonato-scutulate form. They are situated on the outer surface of the inner membrane of the ovarium, with the umbones of the scutellæ outwards. This mode of disposition obviously renders them inefficient for external defence, and the ovaries have therefore been further defended by being enclosed within an elaborately constructed case of reticulated acerate spicula. The gemmule is closely embraced by this envelope, and small elongate masses of its outer surface are projected through some of its interstices, causing it to be more or less tuberculous; and, from the smallness of the interstices, the tubercles of the envelope of the ovary are much greater in length than in thickness. The spicula of the case are disposed in a close and irregular network, seldom exceeding two spicula in thickness. By a careful treatment with hot nitric acid, the thick coriaceous outer portion of the ovarium may be removed, and its thin lining membrane, with its stratum of umbonato-scutulate spicula, becomes an exceedingly beautiful object. The same mode of operation displays the structure of the reticulated case of the ovary very much more distinctly than when viewed in its natural

condition. Fig. 11, Plate XXXIII. represents two of the cases after treatment with acid, one of them (*b*) having the ovary very much reduced in size by the dissolution of the thick coriaceous portion of its structure.

In the second group of the ovaries of the Spongilladæ there is also a strong general resemblance in structure to the type-form of *S. lacustris*, but each species is distinctly characterized by peculiarities of form and arrangement of the spicula.

The normal form is spherical, and the walls of the ovaries, in six out of the seven species with which I am acquainted, are comparatively thin. In the seventh species, *S. Carteri*, Bowerbank (*S. friabilis*, Carter), they are very thick and abundantly furnished with cellular structure, arranged in lines radiating from the centre to the circumference; each line consists of nine or ten cells, the length of each being about equal to the diameter. They are very closely packed together, and are irregularly angular by compression. Their combined length varies from about one-fifth to one-sixth the length of the diameter of the ovarium. This is the only species in which I have detected this description of cellular structure. Fig. 16, Plate XXVIII. represents a portion of the surface and a view of the cells *in situ*.

Although the spiculated coriaceous form of ovarium prevails so constantly among the freshwater sponges, it is one of extremely rare occurrence among the marine species; and I have met with only one instance of its occurrence, and that is in a new genus of sponges from Shetland, for which I am indebted to my indefatigable friend Mr. Barlee. The specimen incrusts a portion of the valve of a *Pecten*, covering a space about half an inch in length and the eighth of an inch in breadth, and it does not exceed half a line in thickness. The ovaries are numerous and closely packed together, and are distinctly visible to the unassisted eye, looking like very minute cocoons of some terrestrial insect. There were nearly thirty in an area equal to about a quarter of an inch. They are attached by the sides to one or more branches of the fibrous portion of the skeleton.

The wall of the ovary is very thin, and appears to consist of a single membrane profusely furnished with acerate spicula, like those of the skeleton. They cross each other in every possible direction, and occasionally appear to assume a somewhat fasciculated arrangement. The ovaries are not uniform in shape, some being regularly oval, while others are more or less ovoid. I could not detect any trace of a foramen in those I subjected to examination. I have designated this interesting species *Diplodemia vesicula* in my MS. description of it. Fig. 1, Plate XXXIV. represents two of the ovaries in their natural condition after immersion in Canada balsam, magnified 83 linear.

In the genera *Geodia* and *Pachymatisma* ovaria are produced in great abundance. They agree in form very closely with those of *Spongilla*, but their structure is widely different, and the soft animal matter that enters so largely into the structure of those of the freshwater sponges scarcely makes its appearance in the ovaries of *Geodia*, their walls being composed of closely packed spicula, firmly cemented together by silex. Their situation in the animal is also different from those of *Spongilla*, in which they are

dispersed amid the interstitial tissues, but principally towards the base of the sponge, while in *Geodia* and *Pachymatisma* they are congregated in large quantities immediately beneath the dermal membrane; and when they have shed their ova they permanently retain their situation, forming a thick crustular dermis for the protection of the softer portions beneath: a few only are found dispersed in the interstitial membranes of the sponge. The progressive development of this kind of ovarium is very nearly the same in every species of *Geodia* or *Pachymatisma* in which I have had an opportunity of examining them. In an early stage they appear as a globular body of fusiformi-acerate spicula, radiating regularly from a central point in the mass. As the individual spicula increase in diameter there is a corresponding distention of the ovarium, and as the spicula do not lengthen in proportion to their increase of diameter a central cavity is produced, in which the incipient ova very shortly appear. The spicula of the wall of the ovary continue to increase considerably in diameter, but very little in length, and their distal terminations become gradually less acute as they approach the period of the full development of the ovary. When this organ has attained its greatest diameter, their distal extremities cease to lengthen, and a gradual change in the form of the spicula is effected, their apices extending in diameter and assuming a truncated form, and the whole of them becoming firmly cemented together, so as to form a common flat smooth surface to the siliceous skeleton of the ovarium, each spiculum having now changed from the acerate to the acuate form, their proximal acute terminations forming the common inner surface of the cavity of the ovarium, which is now filled with an opake mass of ova. A single conical orifice or foramen has also been produced in a portion of the wall, through which the ova are destined to be ejected. The proximal end of this foramen is very much the smaller of the two, so that, as soon as an ovum has fairly entered this conical tube, there is no longer any impediment to its ejection; and the manner in which this is effected is very interesting, and appears to be as follows. When the ova have attained maturity, the proximal terminations of the spicula which have not been cemented together like their distal ones, are progressively and simultaneously lengthened, thereby encroaching on and gradually lessening the diameter of the cavity within, so that the ova are compressed and forced through the foramen; and this process appears to be continued until the whole of them have been ejected, and the cavity becomes completely filled by the continued encroachment of the proximal ends of the spicula of the walls of the ovarium.

In fig. 6, Plate XXXIV., two ovaries from *Geodia M^c^Andrewii* containing ova are represented: (*a*) contains about the greatest quantity of ova that is found within these organs. In this one the distal terminations of the spicula of the skeleton are still somewhat rounded, and slightly elevated above the common surface; while in (*b*), which has been partially exhausted of the ova, the spicula have their distal terminations flat and somewhat angular, and they are level with the general surface, thus indicating a greater age and a fuller development than obtain in the one represented by (*a*), and not a less amount of secretion of ova, as might possibly be imagined. These circumstances are

strongly indicative of the fact that the ovaria, both in an active and an effete state, are permanently seated in the sponge, and that the ova only are discharged from it. So in like manner the existence of the ovarium in *Spongilla reticulata* and *Brownii*, confined within a strong spicula case firmly incorporated with the skeleton, is strong presumptive evidence of their also being permanent organs, and not of the nature of gemmules which separate from the body of the sponge when they arrive at maturity and are ejected through the great fæcal orifice.

Many other species of *Geodia* with which I am acquainted afford these ovaria in great abundance, and with some variations in size and form from those in *G. M^cAndrewii*, but in no other sponge are they so large and so completely developed.

Fig. 2, Plate XXXIV. represents an adult ovarium from *Geodia M^cAndrewii* with the conical foramen on its summit, and the distal ends of the skeleton spicula flat and angular. Fig. 3 represents a small portion of the surface of the same specimen as seen with a linear power of 308, exhibiting the flatness and angularity of their distal apices. Fig. 4 represents a portion of a young ovarium having the distal ends of the skeleton spicula disunited and acutely conical. Fig. 5 represents a portion of a section of an ovarium of *G. M^cAndrewii*, exhibiting the radial arrangement of its component spicula.

In *Pachymatisma Johnstonia*, Bowerbank, a British species common on the rocks in the neighbourhood of Torquay, and which I described in a paper read before the Microscopical Society of London in 1841, these organs assume an oval form; they are also considerably depressed. In a young specimen of this species of sponge in my possession, the progressive development of the ovaria is very strikingly illustrated. Fig. 7, Plate XXXIV. represents an adult ovarium. Fig. 8, one in a semideveloped state, and fig. 9, one of the same organs in a very early stage of development. In another species of sponge from the South Seas we find a singular variety of this class of ovarium. It is oval in form, the length being to the breadth as five to three, but it is so much depressed as to appear rather like a dermal spicula plate than an ovarium; but the radiate arrangement of its component spicula is perfectly visible with a power of 666 linear, and their distal terminations as separate and distinct as those of *Geodia* or *Pachymatisma*. The situation of the foramen is also well defined in many of them. Fig. 10, Plate XXXIV. represents a mature ovarium; fig. 11, a fragment of one to exhibit its degree of thickness; and fig. 12 represents one of the same species of ovarium in an early stage of development. I have seen four species of sponge which have this description of ovarium; in one it is very considerably longer in its proportions than that represented by fig. 10, Plate XXXIV., and in another species it is somewhat shorter.

Since the preceding portion of the account of the ovaria was written I have received a very remarkable specimen of these organs, which differs materially in its structure from any of the forms that I have previously described. The sponge consists of a small portion of basal membrane, closely resembling that of a Halichondraceous species. It was found by my friend Mr. J. Yate Johnston coating rocks and stones at Madeira.

The remains of several exhausted ovaria are dispersed over the surface of the membrane, a few only retaining their original form and proportions. They do not appear to have had a spicular skeleton, but to have consisted of a coriaceous envelope strengthened and supported by a reticulated skeleton of apparently keratose structure. They are nearly globular, and are firmly cemented to the membrane by a broad basal attachment. Although themselves apparently in an effete state, the membrane on which they are seated was in a decidedly living and active condition. It is thickly coated with sarcode, and abundantly furnished with equi-anchorate spicula. Numerous slender acuate or subspinulate spicula are also dispersed over its surface, which are occasionally fasciculated after the manner of the first indications of the formation of a Halichondraceous skeleton. But the most interesting feature of the membrane is, that at intervals over the whole of its surface, and especially at those parts most free from the dispersed spicula, there are small detached groups of spicula, each consisting of two or three irregular fasciculi crossing each other at various angles, resembling in every respect the early stages of development of the gemmules or ova so graphically described by Dr. Grant in his account of the gemmules of the sponge he has designated *Halichondria panicea*. The presence of these early developments of the ova is precisely in accordance with the discharged and effete condition of the ovaries, and is just such an effect as might naturally be expected under such circumstances. Fig. 13, Plate XXXIV. represents one of these ovaria seen by a microscopic power of 108 linear; fig. 14, a small piece of the reticulated wall of the ovarium with a power of 308 linear; and fig. 15 represents the development of one of the ova and the surrounding equi-anchorate spicula with a power of 108 linear.

Gemmules.

If we adopt as a definition that a gemmule is a body not containing ova, but that it is a vital mass separated from the parent and capable of being ultimately developed into a single individual possessing the same specific characters and capabilities as the parent mass, we must consider the reproductive bodies so ably and minutely described by Dr. Grant in his paper "Observations on the Structure and Functions of the Sponge*," not under the designation of ova, but rather under that of gemmules; and indeed the learned author seems to have entertained some doubt of their being correctly designated by the former term, as in speaking of them in a subsequent portion of his paper in page 14, he says, "since these germs or so-named ova are, &c.;" I have therefore been induced to arrange them under the designation of Gemmules.

Dr. Grant describes their first appearance in the sponge in the months of October and November "as opaque yellow spots visible to the naked eye, and without any definite form, size, or distribution, excepting that they are most abundant in the deeper parts of the sponge and are seldom observable at the surface;" he also states that "they have no cell or capsule, and appear to enlarge by the mere juxtaposition of the

* Edinburgh New Philosophical Journal, vol. i. p. 16, plate 2, figs. 24–29.

monad-like bodies around them. As they enlarge in size they become oval-shaped, and at length in their mature state they acquire a regular ovate form." When they have attained a fully-developed condition, they separate from their attachment to the parent and pass out of the fæcal orifices. At this period of their existence the learned author states that they are endowed with spontaneous motion, in consequence of their larger extremity being furnished abundantly with cilia, which the author describes as "very minute transparent filaments, broadest at their base, and tapering to invisible points at their free extremities." After floating freely about for a period, they attach themselves to some fixed body, adhering firmly to it, and spreading themselves out into "a thin transparent convex circular film." The author further states that "when two ova in the course of their spreading on the surface of a watch-glass come into contact with each other, their clear homogeneous margins unite without the least interruption, they thicken, and produce spicula: in a few days we can detect no line of distinction between them, and they continue to grow as one ovum."

I have never had the good fortune to see the living gemmule with its cilia in action, as described by Dr. GRANT, but I have frequently found Halichondraceous sponges with an abundance of these gemmules attached to their tissues; and I have in my possession a beautiful little specimen, dredged off Shetland, for which I am indebted to my kind friend Mr. BARLEE, which is very illustrative of Dr. GRANT's description of the mode of the development of the young sponge after the ovum or gemmule has attached itself. On a fragment of a bivalve shell there are more than twenty or thirty of Dr. GRANT's ova or gemmules, which are all in the same early stage of development, each forming a small group of extremely slender spicula. The groups are separate from each other, but very closely adjoining. The diameter of one of the largest does not exceed $\frac{1}{500}$th of an inch, and their distance from each other is about half or once the diameter of one of them. In their present state, as represented by six of them in Plate XXXIV. fig. 16, it is evident that they are separate developments, and it is equally evident that a slightly further amount of extension would have caused them to merge in one comparatively large flat surface of sponge. We see by this instance that a sponge is not always developed from a single ovum or gemmule, but, on the contrary, that many ova or gemmules are often concerned in the production of one large individual, and this fact may probably account for the comparatively very few small sponges that are to be found; a few days probably serving by this mode of simultaneous development to form the basal membrane of the sponge of considerable magnitude, as compared with the individual ovum or gemmule, or with a sponge developed from a single ovum only. This mode of reproduction appears to have a very wide range. It is common to several distinct genera of Halichondraceous sponges; and I have observed it also in a siliceo-fibrous sponge, *Iphiteon panicea* of the Museum of the Jardin des Plantes, Paris. Fig. 17, Plate XXXIV. represents a small piece from the interior of the skeleton of *Iphiteon panicea*. Although the latter sponge is so widely different in structure from the Halichondraceous tribes of sponges, its mode of propagation by gemmation seems to be in

perfect accordance with them. In *Tethea cranium* the same mode of reproduction by gemmules obtains, but the form of the organ is different, and there are other peculiarities in its growth and development that are extremely interesting.

The form of the gemmules is regularly lenticular; and there are two distinct sorts of them, which are always grouped together. The first is rather the smaller of the two, and has a nucleus of slender curved fusiformi-acerate spicula only. The bases of the spicula cross each other at the centre of the gemmule, and the apices radiate in all directions towards the external surface, but do not, in the fully developed state of the gemmule, project beyond it. The second sort of gemmule is furnished with three distinct forms of spiculum. The first are like those of the gemmule described above, slender fusiformi-acerate; the second are attenuato-porrecto-ternate, the radii being given off from the apex at about an angle of 45 degrees; and the third form is attenuato-bihamate or unihamate, and the hooked apices of this form are projected further than either of the other two forms, but do not pass beyond the inner surface of the tough dermal envelope of the gemmule when in the adult state. I have examined a great number of these gemmules, and could never find in the form first described any indication of either ternate or hamate spicula, and I am therefore satisfied that they are separate descriptions of gemmule, and that the first form is not a transition state from the young and undeveloped to the fully developed one. In like manner I have closely observed the second form, and have always found it uniform in character, and furnished with the whole three forms of spicula that characterize it. It is highly probable that this marked difference in structure is sexual, and, from the more highly developed condition of the second or large form, that it is the female or prolific gemmule; but on this point we must at present be satisfied with conjecture only, as although I have searched diligently for spermatozoa in both forms of gemmule and in the surrounding sarcode, I have not been able to detect anything resembling them. But that such bodies do occur in some species of *Tethea* appears to be the case, Professor Huxley having described and figured bodies which he believed to be spermatozoa in a paper published in the 'Annals and Mag. Nat. Hist.' Second Series, vol. vii. p. 370, plate 14, as occurring in a species of *Tethea* found in one of the small bays in Sydney Harbour, Australia. The group of gemmules represented by fig. 1, Plate XXXV., consists of (*a*) one of the larger and supposed prolific gemmules, and three (*b*, *b*, *b*) of the presumed male gemmules *in situ*, ×108. Wherever the former occurs the latter appear always to accompany them in the proportion of about two or three to one. They are not seated like the ovaria of *Geodia* at the surface of the sponge, but are always found on the interstitial membranes at a considerable depth within the sponge. The immersion of the specimen in Canada balsam has rendered the marginal lines of the gemmules undistinguishable from the surrounding sarcode, but their natural boundaries would be just beyond the extreme points of the spicula.

Fig. 2, Plate XXXV. represents one of the larger gemmules in its natural condition and separated from the sponge, by direct light and a linear power of 50. Figs. 39, 40,

and 43, Plate XXVI. Phil. Trans. 1858, represent the spicula of the larger description of gemmule of *Tethea cranium*, after separation by nitric acid.

The reproductive bodies in the *Tethea* described by Professor Huxley do not resemble those in *T. cranium*; no spicula are either described or figured as existing in them, and in this respect they appear much more to resemble the reproductive organs described by Dr. Grant as existing in the Halichondraceous sponges of the Firth of Forth. But I am not surprised at this discrepancy, as in *Tethea simillima*, Bowerbank, MS., in the collection of the Royal College of Surgeons, from the Antarctic regions of the South Sea, a species very closely resembling *T. cranium*, the gemmules are so like those of the latter species as not to be readily distinguished from them in their natural condition; but when microscopically examined, not the slightest trace could be found of the smaller, and what I conceived to be the male gemmule in *T. cranium*. I have several other species of *Tethea* in my possession, but I have not yet found gemmules in the interior of any of them.

External Gemmulation.

In *Tethea Lyncurium* we have gemmules produced externally, which are perhaps much more entitled to that designation than any of the reproductive organs previously described. The fasciculi near the base of the *Tethea* are protruded considerably beyond the surface of the animal, and at the termination of each there appears a small mass of sarcode, which assumes a more or less globular form. If their bodies be immersed in Canada balsam and examined microscopically, they will be found to contain not only the spicula projected from the parent, but a second series, which have been secreted in the mass, and which have assumed the mode of disposition so characteristic of the skeleton of the parent *Tethea*. I am indebted to my friend Mr. T. H. Stewart for this interesting fact, and for the specimens illustrating it. They were found in Plymouth Sound.

Fig. 19, Plate XXXIV. represents one of these gemmules with a portion of the skeleton fasciculus on which it is produced, under a linear power of 50.

Propagation by Sarcodous Division.

The fact of the resolution of the sarcode of the interstitial tissues of *Spongilla* into small masses of unequal size and variable form has long been known to naturalists, and that when separated from the parent body each becomes capable of locomotion, and of ultimately becoming developed into a perfect sponge. Carter, in his valuable paper published in the Journal of the Bombay branch of the Royal Asiatic Society, No. 12, 1849, has given a minute account of their structure and motions when separated from the species which form the subjects of his paper, and his descriptions are in perfect accordance with the similar bodies separated from our European species *S. fluviatilis*, which I have had frequent opportunities of observing, and of confirming the history given by him of their locomotive powers and continual inherent motions. The author designates these bodies "sponge-cells," and treats of them as if they had a well-defined cell-wall, while their eccentric changes of form are perfectly inconsistent with such a

structure. Lieberkuhn, in treating of these bodies under the name of motile spores, states that he has never succeeded in discerning a "cell-membrane" around these particles, and my own observations are in perfect accordance with his experiences. The truth appears simply to be, that any minute mass of sarcode, whether separated voluntarily or involuntarily, has inherent life and locomotive power, and is capable of ultimately developing into a perfect sponge; and in the course of this process the dermal membrane is produced at a very early period, and this, surrounding an agglomeration of minute masses of sarcode, may have been mistaken by Carter for a cell-membrane. The same author, in his observations "On the Species, Structure, and Animality of the Freshwater Sponges in the Tanks of Bombay," states, "that when the transparent spherical capsules which contain the granules within the seed-like bodies are liberated by breaking open the latter under water in a watch-glass, their first act is to burst; this takes place after the first thirty-six hours; and their granules, which will presently be seen to be the true ova of a proteaniform infusorium, varying in diameter from about the $\frac{1}{4800}$th part of an inch to a mere point, gradually and uniformly become spread over the surface of the watch-glass. On the second or third day (for this varies) each granule will be observed to be provided with an extensible pseudo-pediform base; and the day after most of the largest may be seen slowly progressing by its aid, or gliding over the surface of the watch-glass in a globular form by means of some other locomotive organs."

This description is strikingly similar to the same author's account of the masses of sarcode separated from the sarcodous lining of the interstitial canals of *Spongilla*: but it must be observed that, in the development of the egg, the first act is to liberate itself from the membranous envelope; and the contents thus hatched become moving masses of free sarcode, but without the locomotive cilia that are found on the so-called ova or gemmules of the marine sponges, so minutely and accurately described by Dr. Grant in his papers "On the Structure and Functions of the Sponge" in the 'Edinburgh New Philosophical Journal,' vol. ii. p. 129. This author describes the ovum or gemmule of *Halichondria panicea* (*Hal. incrustans*, Johnston), after having floated freely about for a period by means of the cilia around its larger extremity, as attaching itself to a fixed body by its smaller end and then gradually settling down in the form of a broad flat mass, and, after losing its cilia, being gradually developed in the form of the parent sponge. Thus every description by these close and accurate observers tends to the conclusion that the multiplication of the sponge is effected by the origination in the ovum, or by the agglomeration in the form of gemmules, of particles of sarcode. The action of the minute masses of sarcode liberated by the bursting of the envelope of the ovum, and their subsequent development, are precisely those of the so-called sponge-cell liberated from the mass of the sarcode lining the interstices of the sponge, and of the gemmules described by Grant, when sessile: each moves independently at first; each unites with its congeners into one body; and the results, both in means and end, are precisely the same: but their origin is different. The one is a gemmation of sarcode within a proper membrane in the form of an egg, while the others are the production of a gemmule

by independent growth, or by spontaneous division of the sarcodous substance of the sponge.

Both these modes of propagation occur in the same species, *Spongilla fluviatilis*, but I have never yet seen them both well developed in the same individual. Where the ovaria were abundant, the sarcode appeared even and consistent in its structure; and, on the contrary, if it exhibited manifest symptoms of granulating, very few or none of the ovaria could be detected. This double means of propagation is by no means uncommon among the Zoophytes.

I have never seen the spontaneous granulation of the sarcode in any living marine species of sponge; but as the vital powers and general physiological characters of that substance appear to be the same in all the Spongiadæ, however varied in form and structure, it is highly probable that perpetuation by spontaneous or accidental separation of minute masses of sarcode is by no means confined to *Spongilla*, and that, from the concurrent testimony of all who have investigated the subject, every molecule of sarcode, however minute, has inherent vitality, and the power of uniting with its own congeners whenever they may chance to come in contact.

Growth and Development of Sponges.

The growth of the sponge does not appear to be continuous, but periodical, as we may observe in the branching species, and especially in *H. palmata*. If the sponge be held up between the eye and a lighted candle, as many as five or six of the former pointed terminations of the sponge in succession, from near the base to the apex, may be seen; and the former lateral boundaries are also equally distinct, the oscula being most frequently, but not always, continued through the new coating of the lateral development of the spongeous structure. New branches are also frequently thrown out during the last period of development at various parts of the stem where no indication of branches existed previously. In all these newly-developed parts, it may be observed that the primary lines of the structure of the skeleton, or those radiating at nearly right angles to the axis of the sponge, are those which are first developed; and at the extreme points of the branches they are frequently seen projecting for, comparatively, a considerable distance in the form of single unsupported threads or filaments; but as we trace these lines inward, we find the secondary or connecting fibres increasing in number, and the network becoming closer and more fully developed. The same mode of development may be traced in *Haliohondria oculata*, Johnston, but not to such an extent as in *H. palmata*, Johnston. In the sessile massive species of Halichondroid sponges the same mode of development seems to obtain, as I have frequently traced the different stages of growth in sections at right angles to the surface of the sponge.

Explanation of the Plates.

PLATE XXVII.

Fig. 1. Fibro-membranous tissue in which the layers of fibre cross each other at various acute angles, from *Polymastia robusta*, Bowerbank, MS., ×308 linear: page 751.

Fig. 2. Fibro-membranous tissue in which the layers of fibre cross each other at about right angles, from *Polymastia robusta*, Bowerbank, MS., ×666 linear: page 751.

Fig. 3. Fibro-membranous tissue from the dermal membrane of a species of *Stematumenia*. The fibres are disposed without order, ×183 linear: page 751.

Fig. 4. Fibro-membranous tissue containing a single layer of parallel fibres on a portion of the membrane from an excurrent canal of one of the common honeycomb sponges of commerce, ×666 linear: page 751.

Fig. 5. A portion of the dermal membrane of a young *Stematumenia*, with cells which produce the primitive fibres dispersed on its inner surface:—*a*, *a*, cells *in situ*, which have each produced a fibre, ×666 linear: page 752.

Fig. 6. Three fibres in progressive states of development:—*a*, exhibiting no indications of an ultimate separation from the basal cell; *b*, showing the mature termination of the fibre previous to separation; *c*, exhibiting the collapsed remains of the exhausted basal cell, ×666 linear: page 752.

Fig. 7. Solid keratose fibre from a cup-shaped specimen of the best Turkey sponge of commerce in the condition in which it came from the sea, ×175 linear: page 754.

Fig. 8. Fibres of the skeleton of *Halichondria oculata*, Johnston, illustrating spiculated keratose fibre, ×175 linear: page 755.

Fig. 9. A young fibre of *Halichondria Montagui*, Johnston: *a*, the apical spiculum, ×175: page 755.

Fig. 10. A fibre from the skeleton of *Halichondria ægagropila*, Johnston, illustrating the structure of multispiculated keratose fibre, ×108: page 755.

Fig. 11. A longitudinal section of a small fibre of the skeleton of *Raphyrus Griffithsii*, Bowerbank, MS., showing the irregular disposition of the spicula within it, ×90 linear: *a*, one of the spicula, ×175 linear: page 755.

Fig. 12. Simple keratose fistulose fibre from *Spongia fistularis*, Lamarck, ×108 linear: page 756.

Fig. 13. Compound fistulose keratose fibre from the skeleton of an *Auliskia*, ×100 linear: *a*, *a*, the minute tubular fibres traversing the central cavity of the skeleton-fibre: page 756.

Fig. 14. A portion of one of the skeleton-fibres of *Auliskia*, exhibiting the secondary canals radiating from the primary ones, ×300 linear: page 756.

PLATE XXVIII.

Fig. 1. Regular arenated keratose fibre from the skeleton of a coarse rigid Australian sponge, ×90 linear: page 757.

Fig. 2. Regular arenated keratose fibre from a flexible sponge, one of the common Bahama sponges of commerce, ×175 linear: page 757.

Figs. 3, 4, and 5. Portions of skeleton-fibre from a specimen of *Dysidea fragilis*, Johnston, illustrating the varieties of form of irregular arenated keratose fibre, ×108 linear: page 757.

Fig. 5. Showing the mode by which the apex of the fibre attaches itself to a single grain of sand, ×108 linear: page 757.

Fig. 6. Smooth solid siliceous fibre, with young fibres pullulating from the adult ones at *a*. From the skeleton of *M^c^Andrewsia azoïca*, Gray, ×175 linear: page 758.

Fig. 7. Tuberculated solid siliceous fibre from the skeleton of *Dactylocalyx pumicea*, Stutchbury, ×108 linear: page 758.

Fig. 8. Tuberculated solid siliceous fibre, very prominently tuberculated, from *Dactylocalyx Prattii*, Bowerbank, MS., ×175 linear: page 758.

Fig. 9. Fibrillated sponge-fibre from the skeleton of one of the sponges of commerce, ×308 linear: page 754.

Fig. 10. Fibrillated sponge-fibre from the skeleton of an Australian sponge, ×175 linear: page 754.

Fig. 11. Spinulated simple fistulose siliceous fibre, from a sponge in the collection of Dr. Arthur Farre, *Farrea*, Bowerbank, MS., ×108 linear: page 758.

Fig. 12. Cidarate prehensile fibre from a parasitical siliceo-fibrous sponge from the South Sea, showing the position of the prehensile organs at the base of the sponge, ×83 linear: page 759.

Fig. 13. A group of cells on a portion of the interstitial membrane of *Ecionemia acervus*, Bowerbank, MS., ×666 linear: page 759.

Fig. 14. Cells on a portion of the interstitial membrane of *Halichondria nigricans*, Bowerbank, MS., ×308 linear: page 759.

Fig. 15. Detached nucleated cells from a new species of sponge from Freemantle, Western Australia, ×308 linear: page 759.

Fig. 16. A view of the upper stratum of cells of one of the ovaria of *Spongilla friabilis*, Carter, ×308 linear: page 760.

PLATE XXIX.

Fig. 1. A piece of an interstitial membrane from the honeycomb sponge of commerce in the condition in which it came from the sea, exhibiting the sarcode on its surface, and the imbedded semi-digested minute molecules, ×666 linear: page 760.

Fig. 2. A spinulate spiculum from *Halichœmia patera*, BOWERBANK, MS., ×175 linear: page 766.

Fig. 3. A bispinulate spiculum from the same sponge, ×175 linear: page 766.

Fig. 4. A trispinulate spiculum from the same sponge, ×175 linear: page 766.

Figs. 5, 6, 7. The same forms of spicula as figures 2, 3, and 4, in progressive stages of development, the apices not having attained their acute terminations, ×175 linear: page 766.

Fig. 8. Inner surface of the dermal crust of *Dactylocalyx Prattii*, showing the manner in which the apices of the radii of the ternate spicula are spliced on each other to form the areas for the intermarginal cavities, ×108 linear: page 767.

Fig. 9. Three of the ternate spicula of *Dactylocalyx Prattii*, exhibiting the variations in form and the compressed condition of their radii, ×108 linear: page 767.

Fig. 10. A portion of a thin section at right angles to the surface of a specimen of *Halichondria seriata*, JOHNSTON, illustrating the mode of external defence by the prolongation of the radial lines of the skeleton, ×108 linear: page 769.

Fig. 11. Part of a small branch of *Dictyocylindrus rugosus*, BOWERBANK, MS., exhibiting the radiating structure of the defensive fasciculi, ×50 linear: *a*, a part of the central axis of spicula: page 770.

Fig. 12. A portion of a slice at right angles to the surface from *Tethea cranium*, showing the fasciculi of defensive spicula (*a*), and the mode in which they are supported by buttresses of spicula beneath the surface of the sponge at *b*: *c*, the recurvo-ternate spicula, ×50 linear: page 770.

PLATE XXX.

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Fig. 2. A single mature pedestal, showing its structure and the proportions and positions of the external defensive spicula, ×175 linear: page 771.

Fig. 3. A section of *Hymeraphia stellifera*, BOWERBANK, MS., showing the large bulbous skeleton-spicula *in situ*, their apices forming the external defences: *a*, the stelliferous internal defensive spicula elevated by a grain of sand beneath the basal membrane, ×108 linear: page 771.

Fig. 4. *a*, The basal portion of one of the skeleton-spicula of *Hymeraphia stellifera*, with its large bulbous base, ×260 linear: *b*, one of the stelliferous internal defensive spicula, ×260 linear: page 771.

Fig. 5. A small portion of a longitudinal section through the cloaca of a specimen of *Grantia tessellata*, BOWERBANK, MS., showing the positions of the internal defensive spicula, and their curvature towards the mouth of the cloaca, ×108 linear: page 772.

Fig. 6. A small portion of the kerato-fibrous skeleton of an Australian sponge, showing the attenuato-acuate entirely spined internal defensive spicula *in situ* dispersed on the skeleton-fibre, ×108 linear: page 773.

Fig. 7. Verticillately spined internal defensive spicula dispersed on keratose fibres of the skeleton, from a West Indian sponge, ×175 linear: page 773.

Fig. 8. Verticillately spined internal defensive spicula from a keratose sponge from the West Indies. Congregated in fasciculi, ×175 linear: page 773.

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Fig. 10. A portion of the reticulated skeleton of the sponge, with the radiating fasciculi of spinulo-quaternate internal defensive spicula *in situ*, ×108 linear: page 775.

PLATE XXXI.

Fig. 1. A portion of the reticulated skeleton of a sponge from Madeira, the fibres armed with trenchant contort bihamate spicula, ×50 linear: page 776.

Fig. 2. One of the trenchant contort bihamate spicula, showing the cylindrical form at the curves of the hook and the middle of the shaft, and the trenchant edges of the rest of the inner surfaces of the spiculum, ×400 linear: page 776.

Fig. 3. A portion of the skeleton of *Hyalonema mirabilis*, Gray, showing the mode of disposition of the multihamate birotulate and spiculated cruciform spicula in the body of the sponge. In the collection at the British Museum, ×50 linear: page 777.

Fig. 4. A multihamate birotulate spiculum, magnified 175 linear, to exhibit the peculiarities of its structure: page 777.

Fig. 5. A spiculated cruciform spiculum, to show the relative proportions of the two forms of defensive spicula, ×175 linear: page 777.

Fig. 6. The same form of spiculum as fig. 5, showing the peculiarities of its spination, × 260 linear: page 777.

Fig. 7. A small portion of the skeleton of *Hyalonema mirabilis*?, Gray, from a specimen in the Bristol Museum, showing the reticulations of the skeleton to be abundantly supplied, in some parts, with a small variety of multihamate birotulate spicula: *a*, one of the large spicula, of the same form as those in fig. 5, *in situ*, × 108 linear: page 777.

Fig. 8 represents a small portion of the inner surface of the dermal membrane of *Hymedesmia Zetlandica*, Bowerbank, MS., showing the fasciculation of the simple bihamate spicula, the equi-anchorate ones dispersed singly on the membrane,

and the large attenuato-acuate entirely spined defensive ones *in situ*, × 308 linear: page 780.

Fig. 9. A young circular group of inequi-anchorate spicula, situated on one of the interstitial membranes of *Hymeniacidon lingua*, Bowerbank, MS., × 308 linear: page 780.

Fig. 10. A larger and more complete circular group of inequi-anchorate spicula, containing about the usual number of spicula, from the same sponge as the group represented by fig. 9, × 308 linear: page 781.

Fig. 11. A circular group of torqueato-tridentate inequi-anchorate spicula from the interstitial membranes of a new species of *Hymeniacidon* from Freemantle, Australia, × 308 linear: page 781.

Fig. 12. A single spiculum, from a group similar to that represented by fig. 11, exhibiting the singular structure of the base and the tridentate apex of the spiculum, × 400 linear: page 781.

Fig. 13. A section of *Halichondria panicea*, Johnston, showing the intermarginal cavities at *a*, *a*, immediately beneath the dermal surface, ×108 linear: page 787.

Fig. 14. A small portion of the dermal membrane of *Tethea muricata*, Bowerbank, MS., exhibiting the pores in an open condition, × 108 linear: page 782.

Fig. 15. The lower portion of the same piece of membrane, highly magnified, to show the positions of the elongo-stellate defensive spicula on the external surface of the dermal membrane, × 183 linear: page 782.

PLATE XXXII.

Fig. 1. A section at right angles to the surface of a branch of *Halichondria simulans*, Johnston, exhibiting the form and position of the intermarginal cavities, × 108 linear: page 787.

Fig. 2. A section, at right angles to the surface, of *Geodia Barretti*, Bowerbank, MS.:—*a*, *a*, longitudinal sections of two of the intermarginal cavities; *b*, *b*, the basal diaphragms of the intermarginal cavities; *c*, *c*, imbedded ovaria, forming the dermal crust of the sponge; *d*, *d*, the large patento-ternate spicula, the heads of which form the areas for the valvular bases of the intermarginal cavities; *e*, *e*, *e*, recurvo-ternate defensive and aggressive spicula within the summits of the great intercellular spaces of the sponge; *f*, *f*, portions of the interstitial membranes of the sponge, crowded with minute stellate spicula; *g*, *g*, portions of the secondary system of external defensive spicula, × 50 linear: page 788.

Fig. 3. View of a small portion of the inner surface of the dermal crust of *Geodia Barretti*, Bowerbank, MS., with three of the valvular membranes of the proximal ends of the intermarginal cavities:—*a*, *a*, valves closed; *b*, a valve partly open; *c*, *c*, the radii of the patento-ternate spicula, imbedded in the tissues,

and forming the areas for the support of the valvular terminations of the intermarginal cavities, × 50 linear: page 788.

Fig. 4. Four groups of inhalant pores in the dermal membrane, situated immediately above the distal ends of the intermarginal cavities of *G. Barretti*, × 83 linear: page 794.

Fig. 5. A portion of the dermal surface of *Halichondria panicea*, JOHNSTON, showing the multispicular network for the support of the dermal membrane, and the open pores in the areas, × 108 linear: page 793.

Fig. 6. A small portion of the dermal membrane from *Dictyocylindrus stuposus*, BOWERBANK, MS., exhibiting the number and position of the minute sphero-stellate defensive spicula with which it is armed, × 308 linear: page 793.

Fig. 7. A small portion of the quadrilateral siliceo-fibrous network of the dermis of the sponge upon which Dr. A. FARRE'S specimen of *Euplectella cucumer*, OWEN, is based, showing the double series of entirely spined spicular organs projected from its angles, × 108 linear: page 790.

Fig. 8. A small portion of the single-seried dermal spicular network of *Isodictya varians*, BOWERBANK, MS., × 108 linear: page 792.

Fig. 9. A piece of reticulated kerato-fibrous tissue, for the support of the dermal membrane of one of the species of the common West Indian sponges of commerce, × 108 linear: page 792.

PLATE XXXIII.

Fig. 1. A longitudinal section of the intermarginal cavities of *Grantia compressa*, showing the cilia and their basal cells *in situ*, × 500 linear: page 806.

Fig. 2. A view of a small portion of the inner surface of *Grantia compressa*, exhibiting the oscula open, and the appearance presented at their orifices by the cilia within in action, × 500 linear: page 806.

Fig. 3. Two detached tessellated cells and their cilia, (*a*) in the position of inaction, (*b*) in the position of action, × 1250 linear: page 806.

Fig. 4. A group of detached tessellated cells from the interior of the intermarginal cavities of *Grantia compressa*, × 1250 linear: page 807.

Fig. 5. An ovarium of *Spongilla fluviatilis* in its natural state, exhibiting the foramen, × 83 linear: page 808.

Fig. 6. A small piece of a fibre of the skeleton of one of the common Bahama sponges of commerce, with numerous ova imbedded in its surface, × 400 linear: page 809.

Fig. 7. A small piece of the fibre represented by fig. 6, exhibiting the varieties in form and proportion of the ova, × 1250 linear: page 809.

Fig. 8. View of a section at right angles to the surface of a fragment of the skeleton of the ovarium of *Spongilla fluviatilis*, prepared with nitric acid, exhibiting the

relative positions of the spicula in the skeleton:—*a*, a spiculum from the same ovarium, detached, × 308 linear: page 811.

Fig. 9. A perfect skeleton of an ovarium of *Spongilla fluviatilis*, prepared with nitric acid, × 183 linear: page 811.

Fig. 10. A skeleton of an ovarium of *Spongilla lacustris*, prepared with nitric acid, exhibiting the spicula *in situ* and the foramen, × 183 linear: page 811.

Fig. 11. Two of the reticulated cases of the ovaria of *Spongilla Brownii*, Bowerbank, MS.:—*a*, an empty case; *b*, a case containing the skeleton of an ovarium, × 50 linear: page 813.

Fig. 12. A reticulated case of an ovarium of *Spongilla reticulata*, Bowerbank, MS., × 175 linear: page 812.

Fig. 13. Skeleton of an ovarium of *Spongilla reticulata*, Bowerbank, MS., without its case, prepared with nitric acid, × 175 linear: page 812.

PLATE XXXIV.

Fig. 1. A perfect ovarium of *Diplodemia vesiculata*, Bowerbank, MS., and a portion of a second one, showing the interior and the thickness of its walls in its natural state, × 83 linear: page 813.

Fig. 2. An ovarium of *Geodia M'Andrewii*, Bowerbank, MS., in very nearly an adult state, showing the structure and position of the conical foramen for the discharge of the ova, natural condition, × 183 linear: page 815.

Fig. 3. A small portion of the surface of a fully-developed ovarium of *Geodia M'Andrewii* in its natural state, showing the distal ends of the spicula flat and angular, and firmly cemented together, × 308 linear: page 815.

Fig. 4. A portion of a young ovarium of *Geodia M'Andrewii*, with the distal ends of its spicula acutely terminated, and unconnected, × 308 linear: page 815.

Fig. 5. A portion of a section through nearly the centre of a mature ovarium of *Geodia M'Andrewii*, showing the radiation of its spicula from near the centre to its circumference, × 308 linear: page 815.

Fig. 6. Two ovaria of *Geodia M'Andrewii*, (*a*) containing about the maximum of ova, (*b*) after a great part of the ova have been discharged, × 108 linear: page 814.

Fig. 7. A mature ovarium of *Pachymatisma Johnstonia*, Bowerbank, exhibiting the cuneiform spicula of the foramen, × 308 linear: page 815.

Fig. 8. A young ovarium of *Pachymatisma Johnstonia* in course of development, × 308 linear: page 815.

Fig. 9. A young ovarium of *Pachymatisma Johnstonia* in a very early stage of development, × 308 linear: page 815.

Fig. 10. An ovarium from a sponge from Madeira closely allied to *Pachymatisma*, exceedingly depressed and much elongated, × 308 linear: page 815.

Fig. 11. A fragment of a similar ovarium to that represented by fig. 10, the fracture showing its extremely thin condition, × 308 linear: page 815.

Fig. 12. A young ovarium of the same species as that represented by fig. 10, in an early stage of development, × 308 linear: page 815.

Fig. 13. A reticulated ovarium *in situ*, on the fragment of a sponge from Madeira, × 108 linear: page 816.

Fig. 14. A portion of the reticulated structure from an ovarium of the same description as represented by fig. 13, × 308 linear: page 816.

Fig. 15. An ovum in course of development into a young sponge on the same membrane as that on which the ovarium represented by fig. 13 is seated, × 108 linear: page 816.

Fig. 16. A group of ova or gemmules in course of development into young sponges, found, with many others, on the inner surface of a fragment of a large *Pecten* from Shetland, × 108 linear: page 817.

Fig. 17. A small portion of the skeleton of *Iphiteon panicea* in the Museum of the Jardin des Plantes, Paris, with gemmules *in situ*, × 183 (*Dactylocalyx*, Stutchbury): page 817.

Fig. 18. A gemmule detached from *Iphiteon panicea*, × 666 linear: page 817.

Fig. 19. A gemmule extruded from near the base of a specimen of *Tethea Lyncurium*, on the distal extremity of one of the skeleton fasciculi, × 50 linear: page 819.

PLATE XXXV.

Fig. 1. A group of internal gemmules *in situ*, on the interstitial membranes of *Tethea cranium*:—*a*, one of the larger and most completely organized gemmules; *b*, *b*, *b*, three of the smaller and more simple gemmules which always accompany the larger ones. In Canada balsam, × 108 linear: page 818.

Fig. 2. One of the larger description of gemmules of *Tethea cranium*, in its natural state, removed from the membrane and viewed by direct light, × 25 linear: page 818.

Fig. 3 represents a portion of the sponge from the East Indies, furnished with numerous depressed porous areas with protecting organs, natural size: page 794.

Fig. 4. Two of the inhalant areas, connected by the dermal network:—*a*, the external protective organ in a perfect condition; *b*, having the external protective organ removed to exhibit the deeply depressed porous area, × 50 linear: page 794.

Fig. 5. Half of one of the external defensive organs, highly magnified, to exhibit the disposition of the spicula on the follicular radiations of the organ, × 108 linear: page 794.

Fig. 6. A view of the interior surface of half of one of the external defensive organs, exhibiting the structure of the semifollicular radiations of the organ, × 108 linear: page 794.

Supplement to Part I. "On the Anatomy and Physiology of the Spongiadæ," by J. S. Bowerbank, *LL.D., F.R.S., F.L.S. &c.—Descriptions of New Forms of Spicula that have been discovered since the publication of the First Part* (*Phil. Trans.* 1858, *p.* 279).

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Spicula of the Skeleton.

Farcimulo-cylindrical (Plate XXXVI. fig. 1).—This is the shortest and stoutest form of skeleton-spiculum I have yet seen. It forms the entire skeleton of *Spongilla coralloides*, Bowerbank, MS. A new species from the River Amazon. In the collection of the Royal College of Surgeons of London.

Inequi-acerate vermiculoid (Plate XXXVI. fig. 2).—These spicula are found dispersed in great numbers in the basal membrane of *Hymeraphia vermiculata*, Bowerbank, MS. A new species of British sponge from Shetland. No two of them agree in the form or amount of their contortions, but all of them are more or less inequi-acerate.

Nodulated cylindrical vermiculoid (Plate XXXVI. fig. 3).—The sponge whence this spiculum is derived has not yet been found. It occurs along with inequi-acerate vermiculoid and other well-known forms of sponge-spicula in the soundings from the Atlantic, in 2070 fathoms, and, like the last-named form, no two of them agree in the mode or amount of their contortions.

Elongo-equiangulated triradiate (Plate XXXVI. fig. 4).—An auxiliary skeleton-spiculum from the surface of *Grantia striatula*, Bowerbank, MS. From Madeira. The elongate ray is always disposed in accordance with the long axis of the sponge.

Exflected elongo-equiangulated triradiate (Plate XXXVI. fig. 5).—From the surface near the base of *Grantia striatula*, Bowerbank, MS. From Madeira. The elongated ray in this form, as well as the one represented by fig. 4, varies considerably in its proportions.

Doliolate cylindrical (Plate XXXVI. fig. 6).—From a portion of the skeleton of a sponge nearly related to *Ecionemia*, Bowerbank, MS. Locality unknown.

Bifurcated expando-ternate (Plate XXXVI. fig. 7).—From the same sponge as fig. 6; the shaft of the spiculum assisting in the formation of the skeleton, while the ternate terminations act as external defensive spicula.

Porrecto-ternate (Plate XXXVI. fig. 8).—From the same sponge as fig. 6; the shaft belonging to the skeleton and the ternate apex acting as an external defensive spiculum.

Expando-ternate (Plate XXXVI. fig. 9).—From the same sponge as fig. 6; the

shaft acting as a skeleton-spiculum, while the ternate apex serves as a defensive spiculum.

Geniculated expando-ternate (Plate XXXVI. fig. 10).—From *Tethea Collingsii*, Bowerbank, MS. Sark. The shaft acts as a subsidiary skeleton-spiculum, and the ternate apex as a defensive one.

Abbreviato-patento-ternate (Plate XXXVI. fig. 11).—From a sponge allied to *Pachymatisma*, in the Museum of the Royal College of Surgeons, London. External defensive. The example figured is a fully-developed spiculum.

Inflato-fusiformi-acerate, ascendingly hemi-spinous (Plate XXXVI. fig. 12).—From *Hyalonema mirabilis*, Gray. British Museum. These spicula are projected in great numbers from the dermal surface of the body of the sponge, the smooth basal half being immersed in the tissues beneath the dermal membrane, and the spinous distal portion projected beyond it. The form and mode of disposition of the spines indicate its purely defensive character.

Verticillately spined cylindrical (Plate XXXVI. fig. 13).—This spiculum is very abundant on the dermal and interstitial membranes of an undescribed sponge from Freemantle, Western Australia. It is both externally and internally defensive.

Sub-attenuato, entirely spined cylindrical (Plate XXXVI. fig. 14).—From *Hymeniacidon Cliftoni*, Bowerbank, MS. Freemantle, Western Australia. Internal defensive.

Spiculated inequi-angulated triradiate, with cylindrical entirely spined radii (Plate XXXVI. fig. 15).—From a fragment of a sponge presented to me by Mr. Vickers of Dublin, who thinks it probably came from the West Indies. This spiculum is an external defensive one. The triradiate rays are imbedded immediately beneath the dermal membrane, and the spicular ray is projected through it at right angles to its plane; they are very numerous.

Spiculated attenuato-equiangular triradiate, verticillately spined (Plate XXXVI. fig. 16).—From an undescribed sponge. Freemantle, Western Australia. I have not seen the sponge whence this spiculum is derived, but, reasoning from our knowledge of the form and situation of the spiculum represented by fig. 15, there can be little doubt of its being an external defensive one.

Spiculated cylindro-equiangular triradiate, verticillately spined (Plate XXXVI. fig. 17).—From a fragment of sponge from Freemantle, Australia. This spiculum occurs in the same slide of sponge-spicula as the form represented by fig. 16. It was sent to me by my friend Mr. George Clifton, of Freemantle. There can be little doubt of its being an external defensive organ.

Inequi-furcato-triradiate (Plate XXXVI. figs. 18 & 19).—These forms of spicula are from a new species of calcareous sponge, probably a *Grantia*. They were sent to me, mounted in Canada balsam, by my friend Mr. George Clifton, of Freemantle, Australia. They occur loosely fasciculated, and their mode of disposition is very similar to those represented by figs. 4 & 5, Plate XXXVI. They differ considerably from each

other in length and in the width of the prongs of the fork apart, but they all have them unequal in length. It is probably an auxiliary skeleton and external defensive spiculum.

ELONGO-RECURVATE DENTATO-BIROTULATE (Plate XXXVI. fig. 20).—From *Hyalonema mirabilis*, GRAY. This spiculum is from the same sponge as that represented by fig. 4, Plate XXXI. Part II. It is an extreme variety of that form. Fig. 7, *a*, in the same plate, appears to be an intermediate variety.

ELONGO-RECURVATE DENTATO-BIROTULATE (Plate XXXVI. fig. 21).—From soundings in the Indian Ocean, 2200 fathoms. The smooth shaft and the widely-spread teeth of this spiculum render it very probable that it belongs to an unknown species of *Hyalonema*.

RECURVO-ACUTELY DENTATE BIROTULATE (Plate XXXVI. fig. 22).—From soundings in the Indian Ocean, 2200 fathoms. The thin smooth shaft and the acutely-terminated teeth of this form indicate probably a species of *Hyalonema* unknown to naturalists at present.

RECURVO-DENTATO-BIROTULATE (Plate XXXVI. fig. 23).—From soundings in the Indian Ocean, 2200 fathoms. The fragment represented is most probably from another unknown species of *Hyalonema*. It is the only specimen of this form that has, I believe, been found.

ATTENUATO-CYLINDRICAL, VERTICILLATELY SPINED (Plate XXXVI. figs. 24 & 25).—These spicula are found dispersed in abundance on the interstitial and dermal membranes of *Hymeraphia verticillata*, BOWERBANK, MS. A new British species, brought up by the sounding-line from 100 fathoms, off the Western Coast of Ireland, by the officers of H.M. ship 'Porcupine.' It is remarkable as being the only verticillately-spined spiculum that has been found in a British species of sponge, and also for exhibiting the mode of development of that class of spicula. In the earliest stage the spiculum is long, slender, and perfectly smooth; as the growth proceeds, two or three slight inflations appear near the middle of the shaft, and others are successively developed beyond them, until the spiculum assumes the moniliform appearance represented by fig. 25. As the inflations increase in number and size, a few incipient spines appear in a circumferential line at their greatest diameter; and as the growth proceeds, the spines increase in number and size, and the spaces between the inflations are filled up by the expansion of the shaft; and this mode of development is continued until the adult spiculum assumes the form represented by fig. 24. This form appears to act both as a tension and a defensive spiculum.

Spicula of the Sarcode.

TORQUEATO-BIDENTATE INEQUI-ANCHORATE (Plate XXXVI. fig. 26).—From an undescribed species of sponge. Freemantle, Western Australia. Sent to me, mounted in Canada balsam, by Mr. GEORGE CLIFTON. This is closely allied to the one represented by fig. 12, Plate XXXI. Part II.

Bicalcarate bihamate (Plate XXXVI. fig. 27).—This singular and minute form of spiculum has hitherto been found only in *Isodictya Normani*, Bowerbank, MS. A new British species.

Expando-tridentate equi-anchorate (Plate XXXVI. fig. 28).—From an undescribed sponge in the British Museum. The shaft of this minute spiculum is frequently curved to the extent of nearly a semicircle. Expando-bidentate forms are also mingled with the tridentate ones.

Tridentate fimbriated equi-anchorate (Plate XXXVI. fig. 29).—From *Isodictya fimbriata*, Bowerbank, MS. Shetland. The singular fimbriation of the shaft of the spiculum has never been observed in any other anchorate spiculum. In this sponge the spicula of this form may be traced from the earliest stage of development to the fully fimbriated form exhibited by the one represented by fig. 28. They are very abundant on the interstitial and dermal membranes, and mixed with them; there are many that are only bidentate, but are as completely fimbriated as the tridentate ones. The fimbriæ are very delicate and translucent, and require a careful management of the light to render them apparent.

Quadrihamate (Plate XXXVI. fig. 30).—From *Hyalonema mirabilis*, Gray. These very minute spicula are dispersed in considerable numbers on the interstitial membranes of the sponge.

Inequi-trirotulate (Plate XXXVI. fig. 31).—From an undescribed sponge in the cabinet of my friend Mr. George Clifton, of Freemantle, Western Australia. In Plate XXVI. fig. 38 I have figured a more fully developed specimen of this form, and described it in the 'Philosophical Transactions' for 1858, page 319, believing at that time that it was probably derived from the ovarium of a *Spongilla*. From the structural differences of the two specimens, it is probable that the former one is not from the same species of sponge as the latter.

Eccentric trirotulate (Plate XXXVI. figs. 32 & 33).—From the same sponge as fig. 31. Fig. 33 presents the fully-developed axial eccentricity, while the axis in the spiculum represented by fig 32 is both centrical and eccentrical, and these variations in the mode of the development of the rotulæ are exceedingly common.

Cylindro-cruciform (Plate XXXVI. figs. 34, 35, 36, 37).—From *Hyalonema mirabilis*, Gray. British Museum. These four forms occur in considerable numbers, either imbedded in, or immediately surrounding the thick coriaceous sheath which envelopes the spiral column that is projected from the base of the sponge through its centre. All the imaginable varieties of form between figs. 34 and 37 are found mixed together; and they appear to be especially abundant around that part of the column which is imbedded in the midst of the sponge. The cylindrical form represented by fig. 34 is of rare occurrence without a slight indication near the middle of the absent third and fourth rays of the perfect cruciform spiculum.

Spiculated cylindro-cruciform (Plate XXXVI. fig. 38).—From *Hyalonema mirabilis*, Gray. British Museum. This spiculum is from the sheath of the same sponge as

the previously described forms; the ordinary cruciform spiculum being converted into an external defensive one by the projection of a spicular ray from its centre.

DENTATO-CYLINDRO-HEXRADIATE (Plate XXXVI. fig. 39).—From a unique and very beautiful branching sponge from Nichol Bay, Australia, sent to me by Mr. GEORGE CLIFTON, of Freemantle. The dentation of the radii of these spicula varies considerably in form and size; the number of teeth at the apices of the rays is usually two or three, occasionally four, and very rarely five. The spicula are nearly uniform in size, and extremely abundant on all parts of the interstitial membranes.

EXTER-SPINULATED ARCUATE (Plate XXXVI. fig. 40).—From a small massive sponge from the Bahamas, presented to me by my friend Mr. M^{c}ANDREW. They are very abundantly dispersed over all parts of the interstitial membranes, are uniform in size, and vary to some extent in the degree of spinulation. In Part I. of this paper I described and figured a minute spiculum of the same arcuate form (Phil. Trans. 1858, p. 322, Plate XXVI. fig. 51). I was not aware at that time from what part of the sponge it had been obtained. I have since found the same form abundantly dispersed on the interstitial membranes of a new species of sponge from Freemantle, sent to me by my friend Mr. GEORGE CLIFTON.

SPINULO-MULTIFURCATE HEXRADIATE STELLATE (Plate XXXVI. fig. 41).—This beautiful spiculum forms a connecting link between the spinulo-quadrifurcate hexradiate stellate form and the floricomo-stellate one, described and figured in the first part of this paper (Phil. Trans. 1858, p. 312, Plate XXVI. figs. 2, 3, 4). A careful examination of the specimen presents indications of there having been as many as eight secondary radii at the termination of the primary ray which exhibits the greatest number of secondary ones in the figure; and it is probable that this was the full complement of those parts.

MULTIANGULATED CYLINDRICAL (Plate XXXVI. fig. 42).—From a sponge in the British Museum. This spiculum had been accidentally included in the sponge. It is distinctly different from one of the same form described and figured in the first part of this paper, Phil. Trans. 1858, p. 314, Plate XXVI. fig. 10. It most probably belongs to the sarcode of a *Geodia*.

SPINULO-MULTIANGULATED CYLINDRICAL (Plate XXXVI. fig. 43).—Found among the extraneous spicula of the same sponge as the spiculum represented by fig. 42. This sponge is one of the Johnstonian Collection. It is designated *Halichondria sanguinea*, and its register is 47, 9, 7, 19.

INFLATO-ACERATE, WITH INSCISSURATE TERMINATIONS (Plate XXXVI. fig. 44).—From *Hymeraphia verticillata*, BOWERBANK, MS. A new species of British sponge from the Western Coast of Ireland. A terminal portion only of this spiculum is represented by the figure, the inscissurate character being the only novelty in the form. The inscissuration varies in degree to a considerable extent in different spicula, in some cases being very slightly produced, in others rather beyond that represented by fig. 44. The rudiments of a third ray are sometimes apparent. This form is an auxiliary skeleton-

spiculum. They are found thickly clustered around the primary spicula of the skeleton. They differ essentially from porrecto-ternate spicula in having both ends cleft or radiate, which is never the case in any of the ternate forms.

Explanation of PLATE XXXVI.

Spicula of the Skeleton.

Fig. 1. Farcimulo-cylindrical, from *Spongilla coralloides*, Bowerbank, MS., ×108 linear: page 830.

Fig. 2. Inequi-acerate vermiculoid, from *Hymeraphia vermiculata*, Bowerbank, MS., ×175 linear: page 830.

Fig. 3. Nodulated cylindrical vermiculoid, ×175 linear: page 830.

Fig. 4. Elongo-equiangulated triradiate, from *Grantia striatula*, Bowerbank, MS., ×108 linear: page 830.

Fig. 5. Exflected elongo-equiangulated triradiate, from *Grantia striatula*, Bowerbank, MS., ×108 linear: page 830.

Fig. 6. Doliolate cylindrical, ×175 linear: page 830.

Fig. 7. Bifurcated expando-ternate, ×108 linear: page 830.

Fig. 8. Porrecto-ternate, ×108 linear: page 830.

Fig. 9. Expando-ternate, ×108 linear: page 830.

Fig. 10. Geniculated expando-ternate, from *Tethea Collingsii*, Bowerbank, MS., ×108 linear: page 831.

Fig. 11. Abbreviato-patento-ternate, ×108 linear: page 831.

Defensive Spicula.

Fig. 12. Inflato-fusiformi-acerate, ascendingly hemi-spinous, ×108 linear: page 831.

Fig. 13. Verticillately spined cylindrical, ×666 linear: page 831.

Fig. 14. Sub-attenuato, entirely spined cylindrical, ×400 linear: page 831.

Fig. 15. Spiculated inequi-angulated triradiate, with cylindrical entirely spined radii, ×308 linear: page 831.

Fig. 16. Spiculated attenuato-equiangular triradiate, verticillately spined, ×666 linear: page 831.

Fig. 17. Spiculated cylindro-equiangular triradiate, verticillately spined, ×666 linear: page 831.

Figs. 18 & 19. Inequi-furcato-triradiate, ×183 linear: page 831.

Fig. 20. Elongo-recurvate dentato-birotulate, ×308 linear: page 832.

Fig. 21. Elongo-recurvate dentato-birotulate, ×308 linear: page 832.

Fig. 22. Recurvo-acutely dentate birotulate, ×308 linear: page 832.

Fig. 23. Recurvo-dentato-birotulate variety, ×308 linear: page 832

Fig. 24. ATTENUATO-CYLINDRICAL, VERTICILLATELY SPINED, ×183 linear: page 832.
Fig. 25. The same form of spiculum as that represented by fig. 24, in an early stage of development, ×183 linear: page 832.
Fig. 26. TORQUEATO-BIDENTATE INEQUI-ANCHORATE, ×308 linear: page 832.
Fig. 27. BICALCARATE BIHAMATE, ×1250 linear: page 833.
Fig. 28. EXPANDO-TRIDENTATE EQUI-ANCHORATE, ×1250 linear: page 833.
Fig. 29. TRIDENTATE FIMBRIATED EQUI-ANCHORATE, ×666 linear: page 833.
Fig. 30. QUADRIHAMATE, ×1250 linear: page 833.
Fig. 31. INEQUI-TRIROTULATE, ×666 linear: page 833.
Fig. 32. ECCENTRIC TRIROTULATE, ×666 linear: page 833.
Fig. 33. ECCENTRIC TRIROTULATE, ×666 linear: page 833.
Fig. 34. INCOMPLETELY DEVELOPED, CYLINDRO-CRUCIFORM, ENTIRELY SPINED, ×175 linear: page 833.
Fig. 35. CYLINDRO-CRUCIFORM, PARTLY DEVELOPED AND ENTIRELY SPINED, ×175 linear: page 833.
Fig. 36. CYLINDRO-CRUCIFORM, APICALLY SPINED, ×175 linear: page 833.
Fig. 37. CYLINDRO-CRUCIFORM, ENTIRELY SPINED, ×175 linear: page 833.
Fig. 38. SPICULATED CYLINDRO-CRUCIFORM, ×175 linear: page 833.
Fig. 39. DENTATO-CYLINDRO-HEXRADIATE, ×666 linear: page 834.
Fig. 40. EXTER-SPINULATED ARCUATE, ×1250 linear: page 834.
Fig. 41. SPINULO-MULTIFURCATE HEXRADIATE STELLATE, ×666 linear: page 834.
Fig. 42. MULTIANGULATED CYLINDRICAL, ×400 linear: page 834.
Fig. 43. SPINULO-MULTIANGULATED CYLINDRICAL, ×666 linear: page 834.
Fig. 44. INFLATO-ACERATE, WITH INCISSURATE TERMINATIONS, ×666 linear: page 834.

XXXIII. *On the Oxidation and Disoxidation effected by the Alkaline Peroxides.*

By B. C. Brodie, *F.R.S., Professor of Chemistry in the University of Oxford.*

Received June 19,—Read June 19, 1862.

In a former paper* I communicated to the Royal Society the results of an inquiry as to the cause of the mutual decomposition which takes place between the alkaline peroxides and the oxides of the less electro-positive metals. This decomposition, the first instance of which was discovered by Thénard in the case of the peroxide of hydrogen, had been regarded as of an exceptional and abnormal character, and as such had attracted the attention of chemists and been accounted for by several hypotheses.

These explanations, which attempted to show that the phenomena were caused by the repulsion of particles similarly electrified or were the consequence of the laws of mechanical vibration, assumed their abnormal character, and tended to isolate them from other chemical changes, rather than to comprehend them under the same laws.

In the paper referred to I ventured to suggest that this mode of viewing these decompositions was erroneous, that the phenomena were of a normal character, and were to be regarded as a particular case of those general laws under which all chemical changes are included. On the views there developed, every chemical change is considered as determined by the mutual attraction of particles, or groups of particles, in opposite polar conditions. No *à priori* presumption can be raised that certain particles are susceptible of this polarization, and others not; this point can be determined by experiment alone: and I brought forward several examples, the applicability of which is now very generally admitted, in illustration of the point that the elemental bodies, at the moment of chemical change, exhibit the same phenomena of polarization and are subject to the same laws of diæresis and synthesis as all other chemical substances. On these ideas, as we regard the weight of two volumes of oxygen, that is to say the weight of a molecule of oxygen, O_2, as differing from the weight of two volumes, that is, the weight of a molecule of water, H_2O, in the fact that this weight contains 16 parts of oxygen in the place of 2 of hydrogen, so do we regard the event of the synthesis or diæresis of oxygen as differing from the event of the synthesis or diæresis of water, in the fact that in the one change the two atoms of oxygen fulfil the same functions, and are respectively in the same polar conditions as the two atoms of hydrogen and the one atom of oxygen in the other.

This theory is of a purely relative character; it is connected with no special hypothesis as to the nature of oxygen or water, but it states that, if we make a certain

* See Philosophical Transactions, 1850, Part II. p. 759.

ssertion as to the molecular nature of water, we must, in consistency, make certain parallel assertions as to the molecular nature of oxygen. Our molecular hypotheses may change, but this relation will still remain.

Views as to the polarization of oxygen, and the cause of the decompositions effected by the alkaline peroxides, which to a great extent are identical with the preceding, and in which the same language and the same notation are employed, have recently been put forward, with considerable pretension, as new and originating with himself, by SCHÖNBEIN, Professor of Chemistry at Basle*. This chemist can scarcely be aware of the memoir referred to, as in his numerous publications he makes no allusion to it. A reclamation of a priority of ten years ought not to be required, but I am compelled to call the attention of chemists to these circumstances in order that I myself may not be considered to appropriate without acknowledgment the ideas and discoveries of another.

The decomposition of the alkaline peroxides by the oxide of silver and other similar bodies is complicated by the circumstance that not only is the peroxide decomposed by the metallic oxide, but the reduced silver, which is a necessary product of the action, and also probably the oxide of silver itself is capable of decomposing the peroxide by that continuous form of action which is spoken of as Catalytic. This interferes with the result; the amount of oxygen evolved depends upon the relative velocity with which these two forms of decomposition occur; and while the reduction in equal atomic proportions is never exceeded, and by certain modifications of the experiment may be very closely approximated to, it yet is never absolutely realized, for the catalytic action cannot be entirely eliminated. So that the total loss of oxygen from the oxide of silver in the experiment represents the relation which subsists between these two forms of decomposition, simultaneously occurring, and varies between the limits of the infinite, or catalytic action on the one hand, and the reduction in atomic proportions on the other.

That this is the true account of the phenomena is seen from the fact that, where these disturbing causes do not exist, the decomposition takes place in simple atomic proportions. This was shown to be the case in the decomposition of the peroxide of barium by iodine in the presence of water. The final result of this action is expressed by the equation

$$I_2 + Ba_2O_2 = 2BaI + O_2.$$

It may be considered as taking place by the decomposition and re-formation of water, according to the two equations,

$$I_2 + Ba_2O_2 + H_2O = 2HI + Ba_2O + O_2,$$
$$2HI + Ba_2O = 2BaI + H_2O.$$

* See Annalen der Chemie, vol. cviii. p. 157, SCHÖNBEIN, "Ueber die gegenseitige Katalyse einer Reihe von Oxyden, Superoxyden und Sauerstoffsäuren, &c." Also see Phil. Mag. S. 4. vol. xvi. p. 178, "Further Observations on the Allotropic Modifications of Oxygen, &c."

The parallel character of this reaction to that of the reduction of the metallic oxide is sufficiently evident. Nevertheless it was desirable absolutely to realize the normal change in the case of the oxide itself, and to discover a case in which the catalytic action should be eliminated.

In the paper referred to I gave several examples of the decomposition of the alkaline peroxides, effected by the action of oxidizing substances in aqueous solution—such, for example, as the decomposition of the peroxide of hydrogen by chlorine and by permanganic acid, and of the peroxide of barium by the alkaline hypochlorites and by a solution of ferricyanide of potassium. These reactions are free from the complicating circumstances before mentioned. The present paper contains an investigation of several of these decompositions; it will be seen that they follow the normal law of chemical action, that is, the two substances which enter into the change are decomposed in a simple atomic ratio, and that these decompositions differ from other chemical changes in no single respect, and need, to account for them, no special hypothesis.

The experiment discovered by Barreswil, of the reduction of the peroxide of hydrogen by chromic acid, presents points of special interest. We have in this case an action varying with the proportion present of the decomposing substances, and apparently of an abnormal character, which, however, is shown by accurate investigation to be subject to the atomic law, and to be capable of being broken up into two simple reactions.

From the effects of reduction I proceed to consider the effects of oxidation produced by the alkaline peroxides, which are of considerable theoretical importance. Certain theories have been formed as to the different nature of the oxygen in the different classes of peroxides, based on a supposed difference in the properties of this oxygen. It will be shown that the difference of properties, to account for which these hypotheses have been invented, does not exist, and that, by suitable modification of the circumstances of the experiment, the results of oxidation produced by the peroxide of manganese may equally be realized by the peroxide of barium.

Lastly, I shall give some experiments on the catalytic decomposition which this class of peroxides undergoes, instituted with the view of discovering the cause of this action, and the way in which these phenomena are connected with the ascertained properties of the peroxides. This form of decomposition I believe to be the consequence of that double function of oxidation and reduction which is peculiar to this group of substances.

In the experiments which follow, which were made by means of standard solutions, the amount of solution employed was measured by the aid of a series of carefully calibrated pipettes, which were so arranged that the capacity of each was an exact multiple of the capacity of the smallest pipette. The capacity of this pipette, which I shall designate as P, was equal to 4·55 cub. centims. The other pipettes are designated as 2 P, 3 P, ... 10 P, &c.

The burette employed for titration with permanganate was provided with a glass stopcock; it was etched and calibrated in the same manner as a tube for gas-analysis. The readings were made with a telescope.

The peroxide of barium employed was prepared by precipitation, according to a method elsewhere described. It was free from all impurities, except a trace of carbonate. When a solution of peroxide of hydrogen is spoken of, it is to be understood as the solution of this peroxide of barium in dilute hydrochloric acid.

The solutions of peroxide of sodium were prepared by digestion of the moist and freshly-precipitated hydrate of the peroxide of barium with carbonate of sodium, and filtration from the carbonate of barium formed, or, in some cases, by precipitation of the solution of peroxide of barium in hydrochloric acid by carbonate of sodium, and filtration.

In the numerous experiments and calculations which have been made in the course of the following investigation, and of which a small part only is here recorded, I have been much indebted to the skill and care of my assistant, Mr. F. SCHICKENDANZ.

1. *Decomposition of a Solution of Peroxide of Hydrogen by Permanganic Acid.*

When a solution of permanganate of potassium is mixed with an acid solution of the peroxide of hydrogen, a decomposition of both substances ensues, oxygen gas is evolved, and a colourless solution formed containing a protosalt of manganese.

The proportion in which the substances are decomposed in this reaction was determined in the following manner.

A portion of pure peroxide of barium was dissolved in very dilute hydrochloric acid; a measured quantity of this solution was decomposed by hydriodic acid, and the amount of iodine formed estimated with sulphurous acid, according to the method of BUNSEN.

A measured amount of the solution of permanganate of potassium was decomposed by hydriodic acid, and the iodine formed estimated by the same method.

A measured amount of the solution of peroxide of hydrogen was decomposed by the solution of permanganate, which was added from the burette until the solution was faintly coloured.

Now, if s be the parts of the standard iodine solution required for the decomposition of 1 cub. centim. of the solution of peroxide of hydrogen, and if s_1 be the parts of the iodine solution required for the decomposition of 1 cub. centim. of the solution of permanganate of potassium, where s and s_1, are determined according to the usual formula

$$s=\frac{nt-t_1}{p},$$

and if m be the parts of the solution of peroxide of hydrogen decomposed by the permanganic acid, and m_1 be the parts of the solution of permanganate required to effect their decomposition, and if x be the ratio of the amount of oxygen evolved from the per-

oxide of hydrogen to the amount of oxygen evolved from the permanganate, then

$$x=\frac{ms}{m_1 s_1}.$$

Two distinct series of experiments gave the following results:—

I. $s=14{\cdot}1145$, $s_1=14{\cdot}127$,
$m=4{\cdot}91$, $m_1=4{\cdot}9025$;

whence $x=1{\cdot}0007$.

II. $s=35{\cdot}945$, $s_1=14{\cdot}8$,
$m=4{\cdot}91$, $m_1=11{\cdot}919$;

whence $x=0{\cdot}9945$.

This experiment affords a simple and accurate method of determining by titration with a solution of permanganate the absolute amount of oxygen in a solution of the peroxide of hydrogen.

If e be the amount of oxygen contained in 1 cub. centim. of the permanganate, and y the amount of oxygen in 1 cub. centim. of the peroxide, then

$$y=\frac{m_1}{m}e.$$

In the former of the above experiments 1 cub. centim. of the iodine solution contained 0·00243 grm. of iodine, which are equivalent to 0·00017905 grm. of oxygen.

Hence

The oxygen in 1 cub. centim. of permanganate, as determined with iodine, $=0{\cdot}000517$ grm.;

The oxygen in 1 cub. centim. of peroxide of hydrogen, as determined with iodine, $=0{\cdot}0005147$ grm.;

and

The oxygen in 1 cub. centim. of peroxide of hydrogen, as determined with permanganate, $=0{\cdot}0005144$ grm.

The above experiments prove that in this decomposition the decomposing substances evolve equal quantities of oxygen*; the final result of the change may be thus stated,

$$4HCl+H_2Mn_4O_8+5H_2O_2=4MnCl+8H_2O+5O_2.$$

I have varied this experiment in many ways, by adding the peroxide of hydrogen to the permanganate, and by taking the solutions excessively dilute and excessively concentrated, with the view of eliciting a variation in the reaction, but have constantly obtained one and the same result. Although the above equation expresses accurately the final result of the decomposition, we are not to believe that the five molecules of oxygen are at once eliminated, but rather that the substance passes through five successive stages of disoxidation, very rapidly succeeding one another. If to an excess of an alkaline solution of permanganate an alkaline solution of the peroxide of sodium be added, oxygen is evolved, the solution still remains clear, but becomes of the characteristic green colour of the

* This reaction has also been investigated by Aschoff with the same result.—Répertoire de Chimie pure, vol. iii. p. 296.

manganate of potassium. On the addition of a further portion of the alkaline peroxide, oxygen is again evolved, the solution becomes colourless, and hydrated peroxide of manganese is precipitated. If this precipitate be added to an acid solution of the peroxide of hydrogen, oxygen is again evolved, both the peroxides are destroyed, and a solution is formed of a protosalt of manganese, showing the successive formation and reduction of each of the oxides before the final result is attained.

2. *Decomposition of a Solution of Peroxide of Hydrogen by Ferricyanide of Potassium.*

When an acid solution of the peroxide of hydrogen is mixed with an acid solution of ferrocyanide of potassium, an oxidation takes place, and the ferrocyanide passes into ferricyanide of potassium. This action requires time, and takes place with extreme slowness in dilute solutions.

If, on the other hand, an alkaline peroxide be mixed with an alkaline or neutral solution of ferricyanide of potassium, the reverse action takes place, oxygen gas is evolved, and the ferricyanide passes into the ferrocyanide of potassium.

The proportion in which the substances are decomposed in this reaction was thus determined.

A solution was made of ferricyanide of potassium, of which the value in terms of a standard solution of permanganate of potassium was ascertained as follows. A measured amount of the solution was converted to ferrocyanide by adding to it a great excess of recently precipitated hydrated peroxide of barium, the solution was boiled until the excess of peroxide of barium was completely decomposed, and the amount of ferrocyanide formed was determined by means of the standard solution of permanganate*.

A measured amount of a solution of peroxide of hydrogen, the value of which had been estimated by the process before described in terms of the same solution of permanganate, was precipitated by an excess of baryta water. To this a measured amount of the solution of ferricyanide was gradually added by means of a pipette. After the experiment, the solution was diluted with water and acidulated. The excess of peroxide and the ferrocyanide present was determined by means of the same solution of permanganate.

It is evident that the subsequent addition of permanganate would effect two results,—the decomposition of the excess of peroxide, and the reconversion of the ferrocyanide formed to the condition of ferricyanide.

Since in an acid solution the ferrocyanide is oxidized by the peroxide of hydrogen to ferricyanide, a portion of the ferrocyanide reduced will have undergone that conversion, and an equivalent portion of the peroxide of hydrogen will have disappeared.

Now, putting s=the parts of permanganate solution equivalent to 1 part of the solution of peroxide of hydrogen employed, and s_1=the parts of permanganate solution equivalent to 1 part of the solution of ferricyanide employed,

* This affords an excellent method for the estimation of ferricyanide of potassium.

and putting m=the parts of the solution of peroxide of hydrogen, and m_1=the parts of the solution of ferricyanide respectively decomposed,

and if x=the ratio of the oxygen evolved from the peroxide of hydrogen to the oxygen evolved from the solution of ferricyanide, then

$$x=\frac{ms}{m_1 s_1}.$$

The value of ms is thus given:—

Putting n=the parts of the solution of peroxide of hydrogen employed in the experiment, and p=the parts of the solution of permanganate required after the termination of the reaction,

$$ms=ns-p+m_1 s_1,$$

whence

$$x=1+\frac{ns-p}{m_1 s_1}.$$

In the second of the following experiments the ferricyanide was taken in excess. The experiment was conducted as before, with the exception that the solution of peroxide of hydrogen, having been rendered nearly neutral, was dropped from the pipette into the solution of ferricyanide. The whole of the peroxide is decomposed, in which case

$$n=m, \quad m_1 s_1=p,$$

and

$$x=\frac{ms}{p}.$$

I. $s=1{\cdot}06$, $s_1=0{\cdot}4$,
$n=10$, $m_1=10$, $p=10{\cdot}6$,
$x=1{\cdot}0000$.

II. $s=0{\cdot}76$, $p=7{\cdot}6$,
$n=m=10$,
$x=1{\cdot}0000$.

I have varied the form of these experiments in many ways without producing any variation in the resulting value of x.

The final result of this decomposition is given in the equation

$$2(K_3 Fe_2 Cy_6)+Ba_2 O_2=2(K_3 Ba Fe_2 Cy_6)+O_2.$$

3. *Decomposition of a Solution of Peroxide of Hydrogen by Hypochlorite of Barium.*

When peroxide of barium is mixed with a solution of an alkaline hypochlorite, oxygen gas is evolved, and both substances are decomposed.

The following experiments were made with the hypochlorite of barium. It was prepared by leading chlorine through a solution of hydrate of barium to complete saturation, the excess of chlorine being afterwards expelled by a current of air.

The amount of hypochlorite of barium present in the solution was estimated by decomposing the solution with hydriodic acid, according to the method of BUNSEN.

The value of the solution of peroxide of hydrogen was estimated, as before, with permanganic acid.

When the peroxide of hydrogen was taken in excess, a measured amount of the solution was precipitated by a solution of hydrate of barium. To this a measured amount of the solution of hypochlorite was added by a pipette. After the decomposition, the excess of peroxide of barium was estimated by determination with permanganic acid, the solution being first diluted and rendered acid.

When the hypochlorite was taken in excess, a measured amount of the solution was rendered strongly alkaline with baryta water, and the measured amount of the solution of peroxide of hydrogen added to this by means of a pipette. The excess of hypochlorite present after the decomposition was estimated by the iodine method.

In the former case, putting

s=the parts of permanganate required to effect the decomposition of 1 part of the peroxide of hydrogen employed,

s_1=the parts of permanganate equivalent to 1 part of the solution of hypochlorite of barium employed, as calculated from the determination with iodine,

m=the parts of the solution of peroxide decomposed,

m_1=the parts of the solution of hypochlorite decomposed,

x=the ratio of the amount of oxygen evolved from the peroxide of hydrogen to that evolved from the hypochlorite,

$$x=\frac{ms}{m_1 s_1},$$

where, putting n=the parts of the solution of peroxide employed in the experiment, and p=the parts of permanganate required to decompose the excess of peroxide after the decomposition,

$$ms=ns-p,$$

and

$$x=\frac{ns-p}{m_1 s_1}.$$

In the second case, where the hypochlorite was taken in excess, let

s=the parts of the standard iodine solution equivalent to 1 part of the solution of peroxide of hydrogen;

s_1=the parts of the same solution equivalent to 1 part of the solution of hypochlorite;

m=the parts of the solution of peroxide employed in the experiment;

m_1=the parts of the solution of hypochlorite decomposed;

then, as before,

$$x=\frac{ms}{m_1 s_1},$$

where, putting n_1=the parts of hypochlorite employed in the experiment, and p_1=the parts of the iodine solution equivalent to the excess of hypochlorite present, as determined by experiment,

$$m_1 s_1=n_1 s_1-p_1,$$

and

$$x=\frac{ms}{n_1s_1-p_1}.$$

I. Peroxide of barium in excess.

(1) $n=20$, $m_1=10$,
$s=1{\cdot}015$, $s_1=1{\cdot}113$, $p=9{\cdot}2$,
$ms=ns-p=20{\cdot}3-9{\cdot}2=11{\cdot}1$,
$x=0{\cdot}997$.

(2) $n=2$, $m_1=2$,
$s=4{\cdot}905$, $s_1=0{\cdot}9314$, $p=\left\{\begin{matrix}7{\cdot}923\\8{\cdot}005\end{matrix}\right\}$ Two expts. Mean. $7{\cdot}964$,
$ms=ns-p=1{\cdot}846$,
$x=0{\cdot}99$.

II. Hypochlorite of barium in excess.

$m=10$, $n_1=20$,
$s=3{\cdot}0126$, $s_1=3{\cdot}124$, $p_1=\left\{\begin{matrix}32{\cdot}25\\32{\cdot}4\end{matrix}\right\}$ Mean. $32{\cdot}325$,
$m_1s_1=30{\cdot}155$,
$x=0{\cdot}999$.

The final result, therefore, of the decomposition is in both cases expressed by the equation

$$\mathrm{Ba\,ClO}+\mathrm{Ba_2O_2}=\mathrm{Ba\,Cl}+\mathrm{Ba_2O}+\mathrm{O_2}.$$

I have ascertained by similar experiments that an equivalent of chlorine in aqueous solution decomposes an equivalent of the peroxide of hydrogen, according to the equation

$$\mathrm{Cl_2}+\mathrm{H_2O_2}=2\mathrm{H\,Cl}+\mathrm{O_2}.$$

Decomposition of Chromic Acid by Peroxide of Hydrogen.

The previous reactions are of a normal character. The peroxide of hydrogen and the permanganic acid or alkaline hypochlorite are simultaneously decomposed in simple atomic proportions, and the formation of the oxygen evolved is subject to the general law of atomic combination. The decomposition of the peroxide of hydrogen by chromic acid has a character apparently exceptional, and it is only by an attentive study of the reaction that it is seen to be of the same class as the preceding.

Barreswil made the interesting observation that chromic acid in an acid solution is oxidized by the peroxide of hydrogen, and an evanescent blue compound formed, which is rapidly decomposed with the formation of sesquioxide of chromium and the evolution of oxygen gas. The nature of this compound is unknown. Barreswil, indeed, considered that he had given reasons for believing it to be the chromic compound corresponding to permanganic acid. But he was unacquainted with the peculiar features of the reaction.

Having ascertained, by preliminary experiments which it is unnecessary to detail, that the quantity of peroxide of hydrogen decomposed by the same quantity of chromic acid was variable in amount, and depended upon the proportion in which the two substances were present, I instituted a series of experiments with the view of determining the law of this action.

The absolute amount of the solution of peroxide of hydrogen employed in each experiment was the same, namely 20 P., or very nearly 100 cub. centims. This solution was made up of three parts; of a standard solution of peroxide of hydrogen, of dilute hydrochloric acid, and of water. It is readily seen how, by means of the system of calibrated pipettes before mentioned, the bulk of this solution could be kept constant, while the amount of peroxide of hydrogen contained in it could be caused to vary. The hydrochloric acid employed was excessively dilute, and the same quantity of acid was used in each experiment. I ascertained, however, that the absolute amount of hydrochloric acid used had, within considerable limits, no appreciable influence on the reaction. Into this solution, which was contained in a small flask and kept in a state of rapid agitation during the experiment, the solution of chromic acid was allowed to run freely from the pipette in which it was measured. After the first rapid evolution of oxygen had ceased, and the blue colour had disappeared, the solution was allowed to remain for 16 or 18 hours, and the excess of peroxide of hydrogen was then determined in the manner to be described. In dilute solutions a very considerable time is required for the completion of the reaction.

When the chromic acid was in excess, the experiment was conducted in a precisely similar way, the solution of chromic acid being brought to the standard bulk of 20 P. The result was absolutely the same, whether the peroxide of hydrogen was gradually dropped into the chromic acid, or allowed to run freely from the pipette. On the effects of dilution and temperature I am not yet able to speak with precision; but the solution may at any rate be considerably diluted (for example, mixed with an equal bulk of water) with no appreciable variation in the results.

The value of the solutions of peroxide of hydrogen and of chromic acid employed, was determined by means of the same standard iodine solution and the excess present; after the decomposition, of the peroxide of hydrogen or of chromic acid*, was also estimated in the same manner.

Now, putting

s = the parts of the iodine solution equivalent to 1 part of the solution of peroxide of hydrogen employed;

s_1 = the parts of the same solution equivalent to 1 part of the solution of chromic acid employed;

* Chromic acid cannot be accurately estimated by this method if the solution be very dilute. In strong solutions the error is inappreciable, as I have ascertained by direct experiment. Similar difficulties occur if it be attempted to estimate directly a solution of peroxide of hydrogen by a standard solution of sulphurous acid. To ensure an accurate result, the peroxide of hydrogen must be first decomposed by hydriodic acid, and the iodine formed estimated by sulphurous acid.

m=the parts of the solution of peroxide of hydrogen decomposed in the experiment;

m_1=the parts of the solution of chromic acid decomposed in the same experiment;

x=the ratio of the oxygen evolved from the peroxide of hydrogen to the oxygen evolved from the chromic acid in the same experiment;

then

$$x=\frac{ms}{m_1s_1}.$$

Also, putting

n=the parts of the solution of peroxide of hydrogen employed in the experiment;

n_1=the parts of the solution of chromic acid employed in the same experiment;

r=the ratio of the oxygen contained in the peroxide of hydrogen to the oxygen contained in the chromic acid employed in the experiment;

then

$$r=\frac{ns}{n_1s_1}.$$

This ratio I shall term the ratio of mass.

Further, putting

p=the parts of the iodine solution equivalent to the excess of peroxide of hydrogen after the completion of the decomposition;

p_1= the parts of the iodine solution* equivalent to the excess of chromic acid after the completion of the experiment, as determined by the formula $p=nt-t_1$;

then

$$x=\frac{ms}{m_1s_1}=\frac{ns-p}{n_1s_1-p_1},$$

where either p or $p_1=0$, according as the chromic acid or peroxide of hydrogen is in excess.

And if y be the ratio of the difference of the amount of oxygen contained in the peroxide of hydrogen and the amount of oxygen contained in the chromic acid employed, to the amount of oxygen evolved from the chromic acid decomposed, then

$$y=\frac{ns-n_1s_1}{n_1s_1-p_1}=\frac{n_1s_1}{n_1s_1-p_1}.(r-1).$$

So long as the chromic acid is not in defect, the whole of it being decomposed, $y=r-1$. If the oxygen in the peroxide of hydrogen be equal to that in the chromic acid employed, $y=0$; if this oxygen be greater in amount than that in the chromic acid, y is positive, if less, y is negative.

Also

$$\frac{x}{y}=\frac{ns-p}{ns-n_1s_1}.$$

The numerator of this fraction represents the number of atoms of oxygen evolved

* In these experiments a proportionate part of the solution was titred after the completion of the reaction, and the values of p and p_1 calculated. In strong solutions the error, from this cause, is accumulated and may become considerable. To this may be attributed the deviation from the mean in experiments 1, 3, and 4 of the following Table.

from the peroxide of hydrogen; and the denominator the difference of the number of atoms of oxygen contained in the peroxide of hydrogen, and the number of atoms of oxygen contained in the chromic acid employed in the experiment.

Also if x_1 be the ratio of the total amount of oxygen evolved from the solution, to that evolved from the chromic acid,

$$x_1=\frac{ns+n_1s_1-\overline{p+p_1}}{n_1s_1-p_1}=1+x.$$

The proportion of the oxygen evolved to the whole oxygen taken in the experiment

$$=1-\frac{p+p_1}{ns+n_1s_1}.$$

The annexed Table contains the numerical results of the experiments, and the calculated values of r, x, and y.

Table of Experiments on the Decomposition of Chromic Acid by Peroxide of Hydrogen.

	s.	s_1.	n.	n_1.	p.	p_1.		s.	s_1.	n.	n_1.	p.	p_1.
1.	17·713	51·426	2 P	10 P	0	477·31	22.	18·383	7·413	.....	.....	28·841	...
2.	.....	.....	.....	.....	...	478·50	23.	.....	.....	6 P	4 P	60·014	...
3.	16·831	17·032	2 P	18 P	...	276·05	24.	17·007	6·981	.....	.....	53·708	...
4.	.....	.....	.....	.....	...	276·60	25.	17·594	7·100	.....	.....	57·114	...
5.	.....	.....	2 P	16 P	...	240·23	26.	17·082	6·981	8 P	4 P	86·248	...
6.	.....	.....	.....	.....	...	239·69	27.	17·007	.....	.....	.....	85·760	...
7.	.....	.....	2 P	12 P	...	171·92	28.	.....	.....	.....	.....	86·384	...
8.	.....	.....	.....	.....	...	171·92	29.	.....	.....	10 P	4 P	116·616	...
9.	.....	.....	2 P	8 P	...	103·60	30.	17·23	.....	.....	.....	119·02	...
10.	.....	.....	.....	.....	...	103·99	31.	18·383	7·413	.....	.....	127·23	...
11.	.....	.....	2 P	6 P	...	69·62	32.	17·23	6·981	12 P	4 P	149·88	...
12.	.....	.....	.....	.....	...	69·84	33.	.....	.....	.....	.....	151·48	...
13.	17·042	6·981	2 P	12 P	...	50·26	34.	17·082	6·981	14 P	4 P	182·57	...
14.	.....	.....	.....	.....	...	50·03	35.	18·515	7·413	.....	.....	200·24	...
15.	.....	.....	2 P	6 P	...	10·72	36.	.....	.....	.....	.....	201·04	...
16.	.....	.....	.....	.....	...	11·22	37.	.....	.....	16 P	4 P	236·82	...
17.	16·305	7·415	2 P	4 P	2·906	0	38.	.....	.....	.....	.....	236·82	...
18.	17·183	7·023	.....	.....	0	...	39.	.....	.....	18 P	4 P	272·91	...
19.	17·082	6·981	.....	.....	...	...	40.	.....	.....	.....	.....	273·31	...
20.	.....	.....	4 P	4 P	26·213	...	41.	35·945	7·415	18 P	4 P	585·35	...
21.	17·153	7·023	.....	.....	27·656	...	42.	.....	.....	.....	.....	586·60	...

From these data we obtain the following values for r, y, and x:—

	r.	y.	x.	Mean value of y.	Mean value of x.		r.	y.	x.	Mean value of y.	Mean value of x.
1.	0·068	−12·65	0·959	−12·65	0·975	23.	3·720	2·72	1·696		
2.	.....	.....	0·991			24.	3·648	2·648	1·728	2·691	1·709
3.	0·110	− 9·02	1·103	− 9·02	1·113	25.	3·705	2·705	1·703		
4.	.....	.....	1·123			26.	4·888	3·888	1·803		
5.	0·123	− 7·34	1·042	− 7·34	1·038	27.	4·864	3·864	1·799	3·876	1·811
6.	.....	.....	1·026			28.	. ....	.....	1·833		
7.	0·164	− 5·25	1·037	− 5·25	1·037	29.	6·08	5·08	1·911		
8.	.....	.....	1·037			30.	6·16	5·16	1·905	5·15	1·918
9.	0·247	− 3·16	1·031	− 3·16	1·037	31.	6·20	5·20	1·909		
10.	.....	.....	1·043			32.	7·39	6·39	2·034	6·39	2·000
11.	0·329	− 2·11	1·033	− 2·11	1·035	33.	.....	.....	1·977		
12.	.....	.....	1·037			34.	8·554	7·554	2·023		
13.	0·402	− 1·61	1·017	− 1·61	1·014	35.	8·743	7·74	1·989	7·647	1·992
14.	.....	.....	1·011			36.	.....	.....	1·962		
15.	0·814	− 0·25	1·093	− 0·25	1·103	37.	9·993	8·993	2·003	8·993	2·003
16.	.....	.....	1·111			38.	.....	.....	2·003		
17.	1·100	0·10	1·001	0·10	1·001	39.	11·24	10·24	2·032	10·24	2·027
18.	1·223	0·223	1·223	0·222	1·222	40.	.....	.....	2·022		
19.	1·222	0·222	1·222			41.	21·816	20·816	2·079	20·816	2·061
20.	2·444	1·444	1·506			42.	.....	.....	2·043		
21.	2·446	1·446	1·462	1·457	1·492						
22.	2·480	1·480	1·507								

A graphic delineation of the results is given in the curve annexed, Plate XXXVII.

It will be observed, on inspection of this line, that, so long as the chromic acid is not in defect, the two substances lose equal amounts of oxygen, according to the equation

$$2Cr_2O_3+3H_2O_2=Cr_4O_3+3H_2O+3O_2;$$

that when the amount of oxygen in the peroxide of hydrogen is greater than that contained in the chromic acid, more of the peroxide of hydrogen is decomposed, but never the whole amount taken, and that the amount decomposed increases with the proportion taken until the peroxide of hydrogen contains as much as eight and a half times the amount of oxygen contained in the chromic acid; that after this point the decomposition becomes constant, the peroxide of hydrogen losing twice the amount of oxygen lost by the chromic acid; and that no further increase in the proportion of the peroxide of hydrogen taken causes this limit to be exceeded, the final result of the change being expressed by the equation

$$2Cr_2O_3+6H_2O_2=Cr_4O_3+6H_2O+9O.$$

In what light are we to regard the decomposition between these extreme limits? Are we to consider that the two substances are capable of reacting in any proportion, and that the simple atomic decomposition is the limit of an indefinite action varying according to the mass? or are we not rather to believe that this apparently indefinite action is the sum of certain normal chemical changes which take place in simple atomic ratios, but which vary in absolute amount?

The following experiments indicate that the latter hypothesis is correct, and that the reaction between the extreme limits is not homogeneous, but consists of two chemical

changes which are capable of being separated, from the circumstance that they take place with very unequal rapidity.

A definite period in the decomposition is marked by the disappearance of the blue compound. At this point the solution was titred, and the loss of oxygen estimated. The progress of the decomposition was followed by means of the same experiment until, finally, the maximum loss was attained. I give two series of experiments, in which the substances were taken in different proportions.

I.

Time of titration.	s.	s_1.	n.	n_1.	p.
1. After decomposition of blue compound	17·594	7·160	4 P	4 P	41·98 41·88
2. After ½ an hour	17·183	7·023	4 P	4 P	32·864
3. After 2 hours	——	——	—	—	28·056
4. After 18 hours	——	——	—	—	27·656

These data give the following values for r, y, and x:—

	r.	y.	x.	Mean.
1.	2·47	1·47	0·997 1·0033	1·001
2.	2·446	1·446	1·277	1·277
3.	——	——	1·448	1·448
4.	——	——	1·462	1·462

II.

Time of titration.	s.	s_1.	n.	n_1.	p.
1. Immediate	17·594	7·101	6 P	4 P	76·956 76·207
2. After 1 hour	——	——	—	—	60·12
3. After 1½ hour	——	——	—	—	——
4. After 2 days	——	——	—	—	57·114

Hence we have

	r.	y.	x.	Mean.
1.	3·705	2·705	1·007 1·033	1·020
2.	——	——	1·593	1·593
3.	——	——	1·593	1·593
4.	——	——	1·703	1·703

It thus appears that the decomposition takes place in two stages, the former of which is complete immediately after the destruction of the blue compound, and in which the two substances lose equal amounts of oxygen; while the latter requires several hours for its completion, the solution during this time being in a continual state of change.

It is undoubtedly difficult to speak with any great probability as to the nature of the specific changes which take place, in regard to which many hypotheses may be formed.

The following view, however, is in accordance with the facts.

1. When $x=1$, we have the formation and subsequent decomposition of the substance Cr_4O_9, according to the equations

$$2Cr_2O_3+3H_2O_2=Cr_4O_9+3H_2O,$$
$$Cr_4O_9 \quad =Cr_4O_3+3O_2.$$

2. When $x=2$, after the reaction just expressed the substance Cr_4O_9 is further oxidized to the oxide Cr_4O_{12}, according to the equation

$$Cr_4O_9+3H_2O_2=Cr_4O_{12}+3H_2O.$$

The body Cr_4O_{12} further decomposes with the excess of peroxide of hydrogen present, possibly with the formation of the higher oxide of hydrogen, H_2O_3, and the former product, Cr_4O_9,

$$Cr_4O_{12}+3H_2O_2=Cr_4O_9+3H_2O_3.$$

That the product of the first action is in a continual state of formation and decomposition during the change, is probable from the greater permanence of the blue compound when an excess of peroxide of hydrogen is present: the presence of this body, which in a small excess of peroxide of hydrogen has only a momentary existence, is rendered evident by the duration of the blue colour for as long as ten minutes in the presence of an excess of the peroxide. Lastly, the substance Cr_4O_9 decomposes very much more rapidly than the substance H_2O_3, *i. e.* than the other oxidized product; so that the decomposition can be broken up into its several stages in the manner described, the chemical changes which take place being represented by the system of equations,

$$2Cr_2O_3+3H_2O_2= Cr_4O_9+3H_2O,$$
$$Cr_4O_9+3H_2O_2= Cr_4O_{12}+3H_2O,$$
$$Cr_4O_{12}+3H_2O_2= Cr_4O_9+3H_2O_3,$$
$$Cr_4O_9 \quad = Cr_4O_3+3O_2,$$
$$3H_2O_3 \quad =3H_2O_2+3O;$$

and the result of these changes, by the equation which results from elimination between them, namely,

$$2Cr_2O_3+6H_2O_2=Cr_4O_3+6H_2O+9O.$$

Since the amount of oxygen is in all probability given off in successive stages, we cannot fix with certainty upon any one degree of oxidation as the blue compound*.

* I am unable to reconcile my own results with those of Barreswil, whose experiments appear to have been carefully conducted. The reaction according to this chemist is

$$2Cr_2O_3+H_2O_2=Cr_4O_7+H_2O$$
$$Cr_4O_7 \quad =Cr_4O_3+2O_2,$$

the analogue of permanganic acid being formed. I have not, however, repeated the experiment precisely in the form in which it was made by him, and it is possible that under certain circumstances the oxidation may be arrested at this point. See Annales de Chimie, vol. xx. p. 364.

It may be observed that, if the decomposition of permanganic acid were, as in this case, preceded by an oxidation, the corresponding degree of oxidation would be formed thus:

$$Mn_4O_7 + 5H_2O_2 = Mn_4O_{12} + 5H_2O,$$
$$Mn_4O_{12} = 2Mn_2O + 5O_2.$$

The decomposition of permanganic acid is, in a somewhat strong solution, instantaneous; but it is remarkable that, if the solution of peroxide of hydrogen be very dilute, the addition of the first drops of permanganic acid produce no apparent change. A certain time is required for the commencement of the decomposition, after which it proceeds with regularity. It may be questioned whether this decomposition also may not be effected by successive stages which escape observation, and whether the period which intervenes before the commencement of the action may not be occupied in the production of those substances by the agency of which the final result is attained, and which are successively formed and decomposed.

On the Oxidation effected by the Peroxide of Hydrogen.

We have seen that the peroxides of hydrogen, potassium, and barium possess certain chemical properties which do not belong to the analogous compounds of lead and manganese. An elaborate attempt* has been made to account for the different reactions of the two classes of peroxides, by the assumption that there are two kinds or varieties of oxygen, a positive and a negative variety; it is said that the peroxide of manganese acts as an agent of oxidation because it contains the negative variety, and that the peroxide of barium acts as a reducing agent, because it contains the positive variety of this element. This hypothesis finds its only support in an imperfect and incorrect view of the facts. In truth no such fundamental distinction exists between the properties of the different peroxides as that which it is proposed thus to characterize. The chemical properties of the alkaline peroxides, as of other chemical substances, vary with the conditions in which they are placed, and the substances with which they are associated; and it is in our power so to modify these conditions as to produce with these peroxides the very same effects of oxidation as are produced by the peroxides of the other group. This is evident from the following examples, to which it would be easy to add others:—

1. An acid solution of peroxide of hydrogen causes the conversion of a solution of ferrocyanide to ferricyanide of potassium.

2. An alkaline solution of peroxide of sodium added to a solution of a protosalt of manganese forms hydrated peroxide of manganese.

3. An alkaline solution of peroxide of sodium oxidizes an alkaline solution of sesquioxide of chromium, with the formation of chromate of potassium.

4. A strong solution of hydrochloric acid evolves chlorine with peroxide of barium†.

* Schönbein, Annalen der Chemie, vol. cviii. p. 166.

† Professor Schönbein lays the greatest stress on the different behaviour of the two classes of peroxides with hydrochloric acid. He says, "Die erste Gruppe ist weiter negativ dadurch charakterisirt dass kein ihr angehöriges Superoxyd mit irgend einer wasserhaltigen Säure .... Wasserstoffsuperoxyd zu erzeugen

That there are important differences in the reaction of the peroxide of barium and the peroxide of manganese is not to be denied. But these differences are perfectly conformable to analogy, and are similar in kind to those which distinguish other chemical substances. For experience teaches us that no two chemical substances, however close may be the analogies which connect them, have identical chemical properties. Hydrochloric acid has not all the properties of hydriodic acid; soda has not all the properties of potash; chlorine is not the same as iodine; and sodium is different to potassium. Is it then to be a matter of surprise to us that peroxide of manganese has not all the properties of peroxide of hydrogen? is this case to have a special explanation? and are we to refer the different properties of these substances, not to the actual and known differences in the elements of which they consist, but to an altogether hypothetical and imaginary difference in the oxygen, which is the element common to the two bodies? In each different compound, if such conventional language be admissible, oxygen has different properties; and if we are to account for this class of differences by the assumption of different varieties of oxygen, we must assume not two forms only, but an infinite number of forms of that element. Of the precise mode in which the chemical properties of the compound are connected with the chemical properties of its constituents, we are doubtless unable to give an adequate account. But the fact of this connexion is not to be doubted. We take the oxygen of the peroxide of sodium, and transfer it to the protoxide of manganese. In this new combination it will no longer produce the effects of reduction. Again, we transfer the oxygen of the peroxide of barium to anhydrous acetic acid, and we form one of the most powerful oxidizing agents with which the chemist is acquainted; while we can re-transfer this oxygen to baryta, and restore to it its original properties. It is not the oxygen which is different, but the elements differ with which the oxygen is associated.

The definite manner in which the final result is affected by modifying the conditions of the reaction, is rendered evident by the following series of experiments.

Peroxide of barium, treated with a concentrated solution of hydrochloric acid, evolves chlorine: with a dilute solution of hydrochloric acid, peroxide of hydrogen alone is formed. It was therefore probable that with hydrochloric acid of a certain degree of concentration both reactions would simultaneously occur. This is the case, and the ratio in which the two reactions occur varies with the concentration of the hydrochloric acid, according to a definite law.

A weighed quantity of peroxide of barium was placed in a small flask, to which a delivery tube could be attached by means of a caoutchouc connector. The hydrochloric acid was poured cold upon the peroxide, the delivery tube attached, and the mixture

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vermag, und die zweite Gruppe dadurch, dass keines ihrer Superoxyde unter irgend welchen Umständen aus der Salzsäure oder irgend einem salzsauren Salze Chlor zu entbinden im Stande ist."— Annalen der Chemie, vol. cviii. p. 167. This sweeping statement, in regard to which the truth could have been so readily ascertained, is quite without foundation.

rapidly boiled. The gas evolved was collected over a solution of iodide of potassium: it consisted of a mixture of chlorine and oxygen. The iodine formed was determined by a standard iodine solution in the usual manner. The hydrochloric acid was taken in very great excess; the same absolute amount was used in each experiment, but diluted with varying quantities of water. Since a solution of peroxide of hydrogen is decomposed on boiling into water and oxygen, we may regard the oxygen evolved as the measure of the peroxide of hydrogen formed.

Now, putting

α=the iodine contained in 1 cub. centim. of the standard iodine solution,

s=the quantity of peroxide of barium employed in the experiment,

Z=the quantity of oxygen equivalent to the chlorine evolved,

$nt-t$, with its usual signification,

then

$$Z=\frac{O\times Ba_2O_2}{I\times 0{\cdot}2929}\times\alpha(nt-t_1).$$

In each of the following experiments 25 cub. centims. of concentrated hydrochloric acid were taken. The absolute amount of pure hydrochloric acid in this concentrated acid was experimentally determined; it amounted to 30·33 per cent. α=0·0029735.

Experiment.	Water added.	s.	$nt-t_1$.	Z.	Mean value of Z.
	grm.				
I.	0	0·2929	125·5	8·015	8·015
II. (1)	5	0·3019	129·8	8·047	8·015
(2)	5	0·3008	127·5	7·983	
III.	6·25	0·3006	128·6	7·866	7·866
IV. (1)	7·5	0·2998	122·6	7·654	7·658
(2)	.....	0·3080	126·1	7·662	
V. (1)	10	0·3037	105·9	6·528	6·623
(2)	.....	0·3044	109·3	6·718	
VI. (1)	15	0·2964	65·7	4·188	4·092
(2)	.....	0·3025	64·6	3·997	
VII. (1)	20	0·3006	31·9	1·986	1·962
(2)	.....	0·2985	30·9	1·938	
VIII. (1)	25	0·2981	14·8	0·929	0·936
(2)	.....	0·2990	15·1	0·943	
IX. (1)	30	0·3321	11·6	0·6538	0·677
(2)	.....	0·3071	11·5	0·7005	
X. (1)	35	0·3025	7·5	0·464	0·460
(2)	.....	0·2954	7·2	0·4561	
XI. (1)	40	0·3064	5·7	0·3481	0·326
(2)	.....	0·3084	5·0	0·3035	
XII. (1)	50	0·3144	3·5	0·2083	0·1974
(2)	.....	0·3008	3·0	0·1866	
XIII.	60	0·2973	trace.	.....	.....

Further. Let s= the ratio of the amount of water to the amount of pure hydrochloric acid in the solution of hydrochloric acid employed; and when water is saturated with hydrochloric acid, let s=1; s may be termed the ratio of saturation.

And let d= the amount of water added in each experiment to every 100 cub. centims. of the solution of hydrochloric acid employed.

Now it is estimated that at ordinary temperatures 100 parts of water absorb 38 parts of hydrochloric acid, while the acid employed was found to contain 30·33 per cent.

Hence s in each experiment is determined from the proportion

$$\frac{100}{38} : \frac{100+d}{30{\cdot}33} :: 1 : s,$$

whence

$$s = \frac{38(100+d)}{100 \times 30{\cdot}33} = \frac{38}{30{\cdot}33} + \frac{38 \times d}{3033}$$

$$= 1{\cdot}25 + 0{\cdot}0125 \times d;$$

and if y be put $= s - 1$,

$$y = 0{\cdot}25 + 0{\cdot}0125 \times d;$$

and, lastly, if x be put = the oxygen equivalent to the chlorine evolved, $\frac{1}{3}$ the total oxygen in the peroxide of barium being assumed as 1, we have, assuming 16·02 as the total oxygen

$$8{\cdot}01 : 1 :: Z : x,$$

whence

$$x = \frac{Z}{8{\cdot}01}.$$

We have from the preceding experiments the following values for d, s, y, and x:—

Experiment.	d.		s.	y.	x.
I.	0	0	1·25	0·25	1·000
II.	5	20	1·5	0·50	1·000
III.	6·25	25	1·5622	0·5622	0·9814
IV.	7·5	30	1·625	0·625	0·9567
V.	10	40	1·75	0·750	0·8263
VI.	15	60	2·00	1·00	0·5104
VII.	20	80	2·25	1·25	0·2448
VIII.	25	100	2·50	1·50	0·1167
IX.	30	120	2·75	1·75	0·0844
X.	35	140	3·00	2·00	0·0574
XI.	40	160	3·258	2·25	0·0406
XII.	50	200	3·75	2·75	0·0246
XIII.	60	240	4·25	3·25	trace.

A delineation of the experiments is given in the annexed curve, Plate XXXVIII.

Catalytic Decompositions.

It has now been shown that the alkaline peroxides have a double function, and can be used as agents either of oxidation or of reduction. By certain modifications of the conditions of the experiment, we can produce separately either result. It is not unreasonable to suppose that, among the numerous and varied forms of chemical decomposition, instances would be found in which these phenomena would occur simultaneously. If this were to be the case, the result would be what is termed a contact (or catalytic) decomposition, but caused by two successive changes of a normal chemical character.

That the combination of the oxidizing with the reducing action of the peroxide of

hydrogen is a cause adequate to produce the effects of catalysis, is evident from the following examples.

I. We can successively realize the chemical changes of which the result, as regards weight, is expressed by the equations

$$MnCl+KHO=KCl+MnHO,$$
$$H_2O_2+2MnHO=H_2O+Mn_2H_2O_3,$$
$$H_2O_2+Mn_2H_2O_3+2HCl=3H_2O+2MnCl+O_2.$$

The final result which ensues from the successive performance of these experiments is expressed in the following equation, derived by elimination from the preceding,

$$2KHO+2HCl+2H_2O_2=4H_2O+2KCl+O_2;$$

which equation is again equivalent to the two equations,

$$KHO+HCl=H_2O+KCl$$

and the equation expressive of the catalytic decomposition of the peroxide of hydrogen, viz.

$$2H_2O_2=2H_2O+O_2.$$

II. Again, omitting for the sake of brevity certain circumstances in the reactions, we can produce the results expressed by the equations

$$3H_2O_2+Cr_4O_3=3H_2O+2Cr_2O_3,$$
$$2Cr_2O_3+3H_2O_2=Cr_4O_3+3H_2O+3O_2,$$

whence, by elimination,

$$2H_2O_2=2H_2O+O_2.$$

III. Also

$$2Na_4Fe_2Cy_6+Na_2O_2=2Na_2O+2Na_3Fe_2Cy_6,$$
$$2Na_3Fe_2Cy_6+Na_2O_2=2Na_4Fe_2Cy_6+O_2,$$

whence

$$2Na_2O_2=2Na_2O+O_2.$$

IV. Again,

$$2HCl+H_2O_2=2H_2O+Cl_2,$$
$$Cl_2+H_2O_2=2HCl+O_2,$$

whence

$$2H_2O_2=2H_2O+O_2.$$

Exp. I.—1 P. of an alkaline solution of peroxide of sodium rendered acid and titred, required 9·31 cub. centims. of permanganate solution.

A solution of protochloride of manganese was precipitated by hydrate of sodium, and 1 P. of the above solution added to it. An equivalent portion of the hydrated protoxide was converted into the hydrated peroxide of manganese.

The solution was immediately rendered acid with sulphuric acid, and 2 P. of the same solution added.

After the evolution of gas had ceased, the solution was titred. It required 9·31 cub. centims. of permanganate solution.

3 P. of peroxide had been added, and 2 P. decomposed. The manganese was in the form of protoxide, as at the commencement of the experiment.

Exp. II.—To 1 P. of a solution of ferrocyanide of potassium, which required for its titration 5·96 cub. centims. of permanganate, was added 1 P. of an acid solution of peroxide of hydrogen, which required for titration 3·681 cub. centims. of the same solution of permanganate. An equivalent portion of ferricyanide of potassium was formed.

The solution was rendered alkaline, and to it was added 1 P. of an alkaline solution of peroxide of sodium, which required for its titration 3·33 cub. centims. of the same permanganate solution.

The solution, rendered acid and titred, required 5·66 cub. centims. of permanganate.

Therefore a portion of peroxide equivalent to 7·15 of permanganate had disappeared.

The total peroxide added required 7·01 parts of permanganate.

In these experiments the final is the same as the initial condition of the chemical substances, with the single exception that the peroxide of hydrogen is decomposed. If the oxidation and reduction which in the preceding examples are separately realized had taken place simultaneously and under the same general conditions, no result would have appeared but the decomposition of the alkaline peroxide, and the action would have been termed a contact action. Now, although in the case of the catalytic decomposition of the alkaline peroxide we are undoubtedly not able to specify in each case the precise reaction by which the final result is attained, we have yet in several instances indications that the decomposition proceeds by successive stages of this kind.

When an alkaline solution of peroxide of sodium is added to a solution of protosulphate of manganese, a precipitate is formed of hydrated peroxide of manganese. If, however, a few drops of an excessively dilute solution of protosulphate of manganese be added to an excess of peroxide of sodium, there is no precipitate, but the solution remains clear, becomes brown in colour, and the peroxide undergoes the catalytic decomposition. If a great excess of a solution of the peroxide of sodium be added to a very small quantity of freshly precipitated hydrated peroxide of manganese, the peroxide of manganese dissolves, forming the same clear brown solution. It is thus seen that the peroxide of manganese can be further oxidized by the peroxide of sodium, and that the product of this oxidation decomposes in solution the peroxide of sodium.

Again, if a solution of peroxide of sodium be added to an alkaline solution of permanganate, the latter is first reduced to manganate, the solution becoming green: on further addition of the peroxide of sodium, the solution becomes of the same clear brown colour as that produced by the oxidation of the protoxide. If, however, the peroxide be sparingly added, or if permanganate be added to this solution, a precipitation takes place of peroxide of manganese. It is the compound which forms this brown solution by the agency of which the peroxide of sodium is decomposed; and it is only when the decomposition of the latter is complete, or close upon this point, that the peroxide of manga-

nese appears. The solution then becomes turbid, and the brown flocculent peroxide is precipitated.

It appears therefore, (1) that the protoxide of manganese can be oxidized by the peroxide of sodium to an oxide, forming a clear brown solution; (2) that permanganic acid can be reduced by the peroxide of sodium to the same substance, passing through the condition of manganate; (3) that when the reduction reaches this point, in presence of an excess of peroxide the reduction is for a time arrested, and the catalytic decomposition commences: during this decomposition the brown compound is permanent; and when the peroxide of sodium is nearly decomposed, the reduction again proceeds and peroxide of manganese is formed.

These phenomena may be thus accounted for. There is a point where the oxidizing action concurs with, and as it were meets, the reducing action of the peroxide of sodium; and at this point the catalysis takes place. The peroxide of manganese is formed; but so long as a sufficient excess of the alkaline peroxide is present, it is reoxidized and destroyed as fast as it is produced. By this continuous reduction and oxidation the peroxide of sodium is gradually eliminated. Time is needed for this, as for other chemical changes; but ultimately, when but little peroxide of sodium remains, the peroxide of manganese is precipitated, being produced more rapidly than it is destroyed.

There are other examples of the same class of phenomena. When a solution of peroxide of sodium is added to a solution of a copper salt (sulphate orchloride of copper), at first there is no evolution of oxygen, but a yellowish green precipitate is formed, as was observed by THÉNARD; this precipitate may be thrown on a filter, and for a short time preserved. If a small portion of this precipitate be added to an alkaline solution of peroxide of sodium, bubbles of gas are evolved, and the peroxide of sodium rapidly decomposed. If a solution of peroxide of hydrogen be mixed with a few drops of a weak solution of chloride of copper, and the whole precipitated by baryta water, the same yellow oxide of copper is formed. The peroxide of barium is gradually decomposed; but during the decomposition this yellow oxide is permanent, and only ultimately is it decomposed into hydrated protoxide.

If a very small quantity of an ammoniacal solution of protochloride of copper be added to an alkaline solution of peroxide of sodium, the solution becomes of a yellow colour, and is gradually decomposed. During the whole time of this decomposition, which may be caused to extend over several hours, the yellow colour is permanent; but ultimately, when the whole of the peroxide is decomposed, the blue colour of the ammoniacal solution of the protoxide reappears. The yellow solution of the peroxide of copper, apart from the solution of peroxide of sodium, cannot be preserved for many minutes. The singular permanence of this compound during the decomposition is explained on the hypothesis, that it is continually reproduced as well as destroyed. In this reaction the solution of oxide of copper in potash or ammonia decomposes the alkaline peroxide into oxygen and the alkali, precisely as sulphuric acid in the process of etherification effects

the decomposition of alcohol into ether and water. And we may regard the former event as determined by a series of alternate and inverse changes, analogous to those to which WILLIAMSON has shown the phenomena of etherification to be due, according to the equations

$$Cu_2O + Na_2O_2 = Cu_2O_2^* + Na_2O,$$
$$Na_2O_2 + Cu_2O_2 = Na_2O + Cu_2O + O_2.$$

It may be desirable, for the sake of clearness, to resume the points in the preceding argument. It appears, (1) that by means of the alkaline peroxides we can produce two classes of effects, oxidation and reduction, and this double function is peculiar to this group of peroxides. (2) These peroxides are decomposed by the contact of a great number of chemical substances, and this form of decomposition is also peculiar to the group. (3) The combination of an oxidizing with a reducing action is a cause adequate to produce the results of contact decomposition, and we are able, in certain cases, to imitate, as it were, the contact action by means of a successive oxidation and reduction. (4) There are instances in which we have distinct evidence that the contact decomposition is accompanied by an oxidation and subsequent reduction of the substance by which the action is determined.

In a matter so difficult to submit to the direct test of experiment, it is undoubtedly desirable to offer any view with much reservation; and it would be altogether premature to assert that this is the only form which contact decomposition can assume. Other causes may possibly lead to the same result. At the same time every new case which can be explained on these principles increases the probability of their more extended application, and raises the hope that even these obscure phenomena will ultimately be removed from the domain of conjecture and speculation, and be brought under the methods of experimental research.

* The oxide of copper here formed is probably the sesquioxide, which is also procured by the action of alkaline hypochlorites on the hydrated oxide of copper. The precise nature of this oxide is immaterial to the argument.

XXXIV. *On the Photographic Transparency of various Bodies, and on the Photographic Effects of Metallic and other Spectra obtained by means of the Electric Spark.*

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1. At the Meeting of the British Association held in Manchester last autumn, I exhibited some photographs of spectra from the electric spark obtained between wires of different metals by means of an induction-coil. Upon this occasion a hollow prism filled with bisulphide of carbon was employed, because, owing to its great dispersive power, it furnished spectra in which the lines under examination were more widely separated and exhibited with greater distinctness than by any other medium in ordinary use.

Plate XXXIX. fig. 30 exhibits a copy of the photograph of the solar spectrum obtained by means of a hollow glass prism filled with bisulphide of carbon, contrasted with the spectrum obtained through the same prism simultaneously from the spark between copper terminals of the secondary coil in the induction apparatus. In this, and in all the subsequent figures, the less refrangible end of the spectrum is upon the left-hand side of the Plate.

The great prolongation of the more refrangible portion of the spectrum beyond the part visible to the unaided eye, led me to believe that the bisulphide was a material which exerted but little absorbent action upon the chemical rays. Subsequent experiments have, however, convinced me that this opinion was erroneous, and have rendered it necessary to modify considerably the conclusions deduced from those experiments.

2. At the time that that paper was written, I believed that the photographic effects produced by the electric spectra of all the metals furnished results in a great degree similar to each other, if not actually identical. This, it will be seen from subsequent statements, is correct so far as the fact of the similarity in this portion of the spectra is concerned, but is erroneous as regards the general conclusion deduced from it. During the past winter I have renewed these experiments, substituting a quartz-train for glass and bisulphide of carbon, and have chiefly used a fine quartz prism, kindly lent to me by my friend Mr. Gassiot. The refracting-angle of this prism is about 60°; its faces are about 2 inches long and $1\frac{5}{8}$ inch broad, and are so cut as to furnish a singly refracted beam for the medium rays, by transmitting it along the axis of the crystal. It is well known, from the experiments of Prof. Stokes * and M. E. Becquerel, that quartz is remarkable for its transparency to both fluorescent and phosphorogenic rays of high refrangibility.

* Phil. Trans. 1852, p. 540.

It was soon evident that the absorbent action of the bisulphide was far greater than I had imagined, and that in reality the spectrum which it transmitted was composed of rays which did not extend beyond one-tenth or one-twelfth of the entire length of the spectrum obtained by the use of a quartz-train*.

3. The dispersive power of rock-crystal is, however, comparatively low, and the difficulty of obtaining with it a spectrum free from the effects of double refraction through its entire length is great; so that it appeared to be worth while, as a preliminary inquiry, to ascertain whether any singly refracting medium could be procured, better adapted to researches of this nature by sufficient permeability to the chemical rays, and by tolerably high dispersive power. Although no material on the whole preferable to quartz has been found, the investigation gave results of considerable interest.

4. Before proceeding to detail these results, it will, however, be convenient, as several distinct subjects will be discussed in this paper, to state the order in which I propose to arrange my remarks, and the heads to which they will be referred.

I shall commence with

(1) *The absorption of chemical rays by transmission through different media.*

a. By transmission through solids.

b. By transmission through liquids.

c. By transmission through gases and vapours.

(2) *The absorption of the chemical rays by reflexion* from polished surfaces.

(3) *The photographic effects of the electric spectra of different metals taken in air*, including

a. Pure metals.

b. Alloys.

(4) *Photographic effects of electric spectra of different metals produced by transmitting the sparks through gases other than atmospheric air.*

5. The general results of my experiments upon the absorption of the chemical rays are the following:—

(1) Colourless bodies which possess equal powers of transmitting the luminous rays vary greatly in permeability to the chemical rays.

(2) *Diactinic* solids (that is to say, solids which are permeable to the chemical rays) preserve their diactinic power both when liquefied and when converted into vapour.

(3) Colourless solids which are transparent to light, but which exert a considerable

* The absorptive power of the bisulphide for the chemical rays was, however, noticed by M. E. Becquerel as far back as 1843, as I find by again referring to his paper, Annales de Chimie, sér. 3. vol. ix. p. 301. In this paper M. Becquerel describes the absorbent action of various solids and liquids upon the chemical rays, but, from having used solar light, he failed to remark the great difference between the absorptive powers of quartz and glass. Although he used prisms of rock-salt, rock-crystal, and alum, his results do not indicate the real difference in their absorptive power; and as in all his experiments on liquids he employed a vessel with flint-glass sides to hold them, his conclusions are vitiated by the same error which affected my own earlier inquiries on the subject.

absorptive effect upon the chemical rays, preserve their absorptive power with greater or less intensity both in the liquid and the gaseous state (21).

Whether the compound be dissolved in water or be liquefied by heat, these conclusions are equally true as regards liquids. Water is perfectly permeable to the chemical rays; and this circumstance, conjoined with the fact that in no instance does the process of solution seem to interfere with the special action of the substance dissolved upon the incident rays, renders it practicable to submit to trial a great number of bodies which it would otherwise be impossible to subject to experiments of this nature, owing to the extreme difficulty of obtaining them in crystals of sufficient size and limpidity.

§ 1. ABSORPTION OF THE CHEMICAL RAYS.

a. *By transmission through Solids.*

6. The general arrangement of the apparatus employed in this inquiry is represented in fig. 1, in which the observer is supposed to be looking down upon the instrument. *c*, *c* is a camera which allows of a considerable range of adjustment, and is attached to a cylindrical box, within which is a prism *b*, of rock-crystal. At *l* is a quartz lens of $1\frac{1}{4}$-inch aperture, and $17\frac{1}{3}$ inches focal length. At one end of the tube *t*, which can be

Fig. 1.

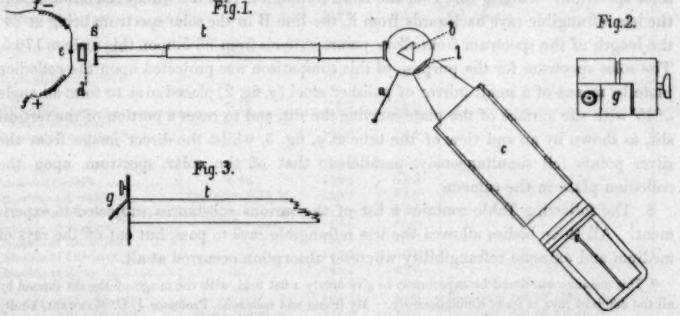


Fig. 2.

Fig. 3.

lengthened or shortened by a sliding joint, is a slit *s*, provided with a screw for regulating the width of the opening. This slit is arranged parallel to the axis of the prism, and in these experiments was adjusted to a distance of 37 inches from the lens *l*. The prism is placed at about its angle of minimum deviation for the mean ray, and, for facility of manipulation, can be turned round upon its own axis by means of the lever *a*. The angle formed between the camera and the tube *t* also admits of variation as circumstances may require. At *d* is placed the substance the transparency of which is to be tested; and at *e* are the metallic electrodes, which are connected with secondary wires *f f* of a 10-inch induction-coil, not shown in the figure. The wires of the coil terminate in electrodes composed of fine silver. The coil was excited by means of a battery consisting of five

elements of GROVE's construction, a condenser being included in the primary circuit, whilst a small Leyden jar, exposing about 75 square inches of metallic coating upon each of its surfaces, was introduced into the secondary circuit. In this way a torrent of sparks could be maintained between the electrodes at *e* without any sensible variation of power, for ten minutes at a time, or longer if necessary. In these experiments, an exposure of the sensitive plate for five minutes in the camera was requisite.

At a suitable distance behind the lens (about 26 inches*), a collodion plate coated with iodide, or occasionally with a mixture of iodide and bromide of silver, was supported in the camera, for the purpose of receiving the image of the spectrum †. The plate was excited by the use of a bath of nitrate of silver containing 30 grains of the nitrate to an ounce of water. The image was developed in the usual way by means of pyrogallic acid, in the proportion of one grain to the ounce of water, and fixed with cyanide of potassium.

7. The spectra of electric sparks so obtained were remarkable for their great length; indeed they extended beyond the termination of the visible rays for a space equal to five or six times the length of the luminous portion.

For the convenience of comparing the results of the various experiments together, I have adopted an arbitrary fixed scale, the fiducial point of which is the line H in the solar spectrum. Calling this 100, the more refrangible rays are numbered onwards, and the less refrangible rays backwards from it, the line B in the solar spectrum being at 84: the length of the spectrum from silver points extends from 96·5 upon this scale to 170·5. The solar spectrum for the purpose of this comparison was projected upon the collodion plate by means of a small mirror of polished steel (*g*, fig. 2) placed so as to form an angle of 45° with the surface of the plate carrying the slit, and to cover a portion of the vertical slit, as shown by an end view of the tube at *g*, fig. 3, whilst the direct image from the silver points fell simultaneously, parallel to that of the solar spectrum, upon the collodion plate in the camera.

8. The following Table contains a list of the various substances subjected to experiment. All these bodies allowed the less refrangible rays to pass, but cut off the rays of medium and extreme refrangibility wherever absorption occurred at all.

* This distance was found by experiment to give nearly a flat field, with the image of the slit formed by all the different rays in focus simultaneously. My friend and colleague, Professor J. C. MAXWELL, kindly calculated for me the relative positions of lens and prism necessary to ensure an approximatively flat field for the visible rays.

If the lens be placed between the slit and the prism, a very great difference occurs between the points of convergence of the most refrangible and the least refrangible rays, amounting with the lens and prism which I used to nearly 14 inches. When the lens is before the prism, both coincide in augmenting the convergence of the more refrangible rays; whereas when the lens is placed behind the prism, as shown in the figure, the convergence occasioned by the lens is neutralized by the prism, which now acts in the opposite direction upon the diverging rays as they fall upon it from the slit.

† My friend Mr. PIZEY, who assisted me in these experiments, prepared the collodion for me, following nearly the directions given by HARDWICH in his 'Manual of Photographic Chemistry,' 6th edition, p. 262. It was iodized with a mixture of equal parts of iodides of potassium and cadmium, and was perfectly uniform in its action, even for weeks after it had been iodized, if kept in the dark.

TABLE I.—Diactinic Power of Solids.

Name of substance.	Thickness, in inches.	Termination of spectrum.	Relative lengths of spectra.	Remarks.
Ice	about 0·5	170·5	74·0	
Diamond* (*l*)	0·032	155·5	59·0	
Diamond (*m*)	0·017	159·5	62·0	
Diamond (A)	0·182	115·5	19·0	
Sapphire (24)	0·13	116·0	19·5	
Sapphire (B)	0·093	112·0	15·5	Faint bluish tinge.
Sapphire (*n*)	0·12	111·0	14·5	
Quartz	0·16	170·5	74·0	With quartz-train.
White Topaz	0·19	162·0	65·5	Faint image of spectrum.
Mica	0·007	114·5	18·0	
Oil of Vitriol	0·75	160·5	64·0	
Sulphate of Lime (solid)	about 0·3	155·5	59·0	
Sulphate of Baryta (solid)	about 0·4	154·5	58·0	
Sulphate of Magnesia (solid)	0·34	158·0	61·5	
Sulphate of Potash	Sat. soln. 0·75 in.	159·5	63·0	
Sulphate of Soda	„	159·5	63·0	
Sulphate of Ammonia	„	145·5?	49·0?	
Sulphate of Zinc	„	152·5	56·0	
Alum	„	159·5	63·0	
Sulphate of Iron	„	105·0	8·5	Pale green.
Sulphate of Manganese	„	144·5	48·0	Faint pink.
Sulphate of Copper	„	112·5	16·0	Full blue.
Sulphite of Soda	„	127·5	31·0	
Hyposulphite of Soda	„	108·5	12·0	
Fluor-spar	0·17	170·5	74·0	
Fluoride of Sodium	Sat. soln. 0·75 in.	159·5	63·0	
Fluoride of Ammonium	„	166·5	70·0	
Hydrochloric Acid, sp. gr. 1·1	0·75 in.	152·5	56·0	
Rock-salt (solid)	0·75	159·5	63·0	
Chloride of Potassium	Sat. soln. 0·75 in.	159·5	63·0	
Chloride of Ammonium	„	155·0	58·5	
Chloride of Barium	„	153·0	56·5	
Chloride of Strontium	„	152·0	55·5	
Chloride of Calcium	„	147·0	50·5	
Chloride of Zinc	„	145·5	49·0	
Chloride of Manganese	„	104·5	8·0	Faint rose-colour.
Chloride of Tin ($SnCl$)	„	108·5	12·0	Spectrum cut off abruptly.
Chloride of Tin ($SnCl_2$)	Strong solution.	114·5	18·0	Spectrum cut off abruptly.

* I am indebted to my friend Professor W. H. MILLER, of Cambridge, for the opportunity of examining the diamonds and sapphires alluded to above. *l* was a slice of diamond bounded by cleavage-planes, from the Warburton Collection. *m* a somewhat thicker slice from the same collection. A a large octahedral diamond from the Humian Collection: all these were colourless. The sapphire 24 was a large six-sided prism from the Brooke Collection; that marked B was a smaller prism of a faint bluish tinge from Professor MILLER's own collection. *n* is a colourless crystal of sapphire from the Warburton Collection. I made an application to the Trustees of the British Museum for permission to use some of the limpid specimens in their collection, but was informed that even for such a purpose the Act of Parliament forbids them to allow any mineral to pass off their premises. Mr. Maskelyne was kind enough to lend me a fine colourless topaz from his own collection.—[Feb. 1863.]

TABLE I. (*continued*).

Name of substance.	Thickness, in inches.	Termination of spectrum.	Relative lengths of spectra.	Remarks.
Chloride of Arsenic ($AsCl_3$)...	Liquid.	101·5	5·0	Spectrum cut off abruptly.
Corrosive Sublimate	Sat. soln. 0·75 in.	128·5	32·0	Spectrum cut off abruptly.
Bromide of Sodium	"	144·5	48·0	
Bromide of Potassium	"	144·5	48·0	
Iodide of Sodium	"	114·5	18·0	Spectra terminate abruptly.
Iodide of Potassium	"	114·5	18·0	
Cyanide of Potassium	"	105·5?	9·0?	Prepared by LIEBIG's process.
Cyanide of Mercury	"	145·5	49·0	
Sulphocyanide of Potassium...	"	112·5?	16·0?	Slightly yellowish.
Hydrate of Soda	"	131·5	35·0	From sulphate by precipitation with baryta.
Hydrate of Potash.....	"	129·5	33·0	
Hydrate of Ammonia	Sp. gr. 0·945	170·5	74·0	Rather feeble spectrum.
Hydrate of Baryta	Sat. soln. 0·75 in.	158·0	61·5	
Hydrate of Strontia	"	150·0	53·5	
Hydrate of Alumina	Strength of solution	146·0	49·5	CRUM's solution.
Hydrate of Silica	not determined.	152·0	55·5	Dialysed from hydrochloric solution.
Carbonate of Soda	Sat. soln. 0·75 in.	146·0	49·5	
Carbonate of Potash	"	146·0	49·5	From ignited bicarbonate.
Iceland Spar	0·35	160·0	63·5	
Bicarbonate of Soda	Sat. soln. 0·75 in.	145·0	48·5	
Bicarbonate of Potash	"	142·0	45·5	
Sesquicarbonate of Ammonia .	"	152·0	55·5	
Boracic Acid	"	143·0	46·5	Faint beyond 109.
Borax	"	158·5	62·0	
Phosphoric Acid	"	117·5?	21·0	
Phosphate of Soda ($HO, 2NaO, PO_5$)	Solution of 60 grains of dried salt in 1 oz. of water.	156·5	60·0	Equal weights of same salt; one dried at 300° F., the other ignited.
Pyrophosphate of Soda, $2NaO, PO_5$		156·5	60·0	
Triarseniate of Soda ($3NaO, As\,O_5$)	Sat. soln. 0·75 in.	127·5	31·0	
Arsenic Acid.....	"	119·5	23·0	
Chlorate of Potash.....	"	145·5	49·0	
Nitric Acid	Sp. gr. 1·3	106·5	10·0	Colourless.
Nitrate of Soda	Sat. soln. 0·75 in.	112·5	16·0	All the spectra of the nitrates are cut off sharply.
Nitrate of Potash	"	112·5	16·0	
Nitrate of Ammonia	"	112·5	16·0	
Nitrate of Lime.....	"	112·5	16·0	
Nitrate of Magnesia	"	112·5	16·0	
Nitrate of Baryta	"	111·5	15·0	
Nitrate of Strontia.....	"	111·5	15·0	
Nitrate of Nickel	"	absorbed	0·0	Intense green solution.
Nitrate of Lead	"	111·5	15·0	
Subnitrate of Mercury	"	111·5	15·0	
Nitrate of Silver	"	106·0	9·5	

TABLE I. (*continued*).

Name of substance.	Thickness, in inches.	Termination of spectrum.	Relative lengths of spectra.	Remarks.
Acetic Acid	Glacial, liquefied	112·5	16·0	Spectrum ends abruptly.
Acetate of Soda	Sat. soln. 0·75 in.	144·5	48·0	
Acetate of Potash	"	113·5?	17·0?	
Acetate of Ammonia	"	144·5	48·0	
Acetate of Baryta	"	115·5?	19·0?	Very faint brownish tinge in liquid.
Acetate of Lime	"	115·5?	19·0?	
Acetate of Lead	"	130·5	34·0	
Tartaric Acid	"	127·5	31·0	
Tartrate of Soda	"	144·5	48·0	
Tartrate of Potash	"	144·5	48·0	
Rochelle Salt ($NaO, KO, C_4H_4O_{10}$)	"	144·5	48·0	
Tartar Emetic ($KO, SbO_3, C_4H_4O_{10}$)	"	131·5	35·0	
Citric Acid	"	133·5	37·0	
Oxalic Acid	"	114·5	18·0	
Oxalate of Potash	"	117·5	21·0	
Oxalate of Ammonia	"	124·5	27·0	
Sugar-candy	60 grains in 200 grains of water.	156·5	60·0	
Milk-sugar		151·5	55·0	
Gum-arabic	Mucilage.	113·5?	16·0	Slightly opalescent.
Silicate of Soda	Sat. soln. 0·75 in.	108·5	12·0	
Faraday's Optical Glass	0·54	101·5	5·0	Pale yellow.
Flint-glass	0·68	105·5	9·0	
Window Sheet-glass	0·07	112·5	16·0	
Hard Bohemian Glass	0·18	114·5	18·0	
Plate-glass	0·22	111·5	15·0	
Crown-glass	0·74	106·5	10·0	Greenish.
Thin Glass for Microscope	0·009	116·5	20·0	

The photographic impression of each spectrum in every case quoted in this Table commences at 96·5, and the number inserted in the Table in the second column of figures indicates the point at which the most refrangible rays transmitted by the compound under examination ceased. The numbers in the third column of figures represent the length of the spectrum, the unit of the scale being one millimetre.

9. In the majority of cases of saline compounds in the foregoing Table the results given are those obtained by forming a saturated solution of the compound in distilled water, and decanting the liquid after it had become clear by standing. It is not advisable to filter in these cases, as the introduction of minute quantities of certain compounds, especially of some of organic origin, greatly impairs the transparency of the liquid to the rays which produce chemical action.

The solution, duly prepared, was then placed in a small trough made by cutting a notch in a piece of plate-glass $\frac{3}{4}$ inch in thickness, the sides of the trough being completed by thin plates of polished quartz, which were pressed by means of bands of

caoutchouc against the ground surfaces of the plate-glass. No cement was employed, and the trough was taken to pieces and cleansed between each experiment—a stratum of liquid 0·75 inch thick being used in each case.

10. In the preparation of the various compounds for examination, much care was taken to employ the materials in a state of purity. In one or two instances, however, it has happened that an acid which usually forms highly diactinic salts has exhibited an anomalous and excessive absorptive power, although in combination with a base which in other instances furnishes strongly diactinic salts. Here some impurity, in quantity so small as to escape the tests in ordinary use, but sensitive to the action of light, has probably been present, and has impaired the diactinic capacity of the substance. Cases in which such impurity is suspected are indicated in the Table by the mark (?) subjoined to them. I intended to have prepared fresh portions of each of these substances with a view to their re-examination; but by the time I had arrived at this stage of my experiments I learned from my friend Professor STOKES that he had been engaged in a similar inquiry, but had been turning to account for this purpose the property of fluorescence; and as I found that my results, where both of us had employed the same substance, were in close accordance with those which he had obtained, I determined to postpone the further examination of these bodies till after the details of Professor STOKES's experiments have appeared. I have also refrained from extending my observations to the compounds of organic chemistry, many of which I had otherwise proposed to submit to a similar investigation.

It may here be observed that the solution of a salt in water always to a certain extent impairs the diactinic quality of the liquid, however limpid the solution may be, producing an effect which may be compared to opalescence or turbidity in a liquid employed in the transmission of luminous rays.

11. I have not been able to trace any special connexion between the chemical complexity of a substance and its diactinic power. Carbon in its pure form as diamond we regard as an element. In thin slices it transmits portions of the chemical rays of nearly all degrees of refrangibility, though none of the specimens which I examined exhibited any approach to the actinic limpidity of quartz. Phosphorus, on the other hand, though transparent to light in its melted condition, and equally regarded as elementary, appears to be nearly *adiactinic*, or impermeable to the chemical rays. In many cases the peculiar diactinic or adiactinic action of an element is traceable in its simpler chemical compounds. Thus the simpler combinations of sulphur, such as sulphuretted hydrogen, sulphurous acid gas, bisulphide of carbon, and chloride of sulphur, are all powerful actinic absorbents, while in the more complicated form of sulphuric acid and the sulphates of certain bases the compounds are highly diactinic. On the other hand, the silicates are much less diactinic than silica in the form of quartz, or the bases which enter into the formation of the silicates: probably this may arise, as Professor STOKES suggests, from the difficulty of obtaining silicates, either natural or artificial, after fusion, perfectly free from iron.

12. No solid or liquid substance that I have as yet tried surpasses rock-crystal in

permeability to the rays which excite chemical action. Ice (and water), as well as white fluor-spar, rival it; and pure rock-salt approaches it very closely *. White topaz is a little inferior to the preceding bodies in diactinic capacity.

Amongst the various compounds submitted to examination, the *fluorides* rank first in diactinic power; then follow the *chlorides* of the metals of the alkaline earths. The *bromides* of the same metals appear to be less diactinic than the fluorides and chlorides, and this decline in power is still more marked in the case of the *iodides*. The short spectrum of these last-mentioned salts is interrupted by a well-marked absorption-band at a point beyond H, represented on the arbitrary scale at 103·5, beyond which the spectrum is again faintly renewed to 113·5, and then it terminates abruptly. The *cyanides* appear to be considerably diactinic; but further experiments upon these salts, as well as upon the *sulphocyanides*, are desirable. *Sulphuric*, *carbonic* and *boracic* acids furnish salts with the alkalies and alkaline earths, which are also largely diactinic: the *phosphates* seem to be less so, and the *arseniates* still less. It is remarkable that though the sulphates are so diactinic, the *sulphites* are considerably less so, and the *hyposulphites* are more opaque than the sulphites. The *hydrates* of the alkaline earths are also transparent. It is very difficult to obtain the alkaline hydrates perfectly pure; but a solution of hydrate of soda and one of potash, furnished by precipitation of their respective sulphates by means of baryta, and concentrated in a silver dish, gave a very fair result in each case.

The diactinic capacity of the *tartrates* and *citrates* is less than that of the carbonates. That of the *acetates* appears to be about the same as that of the tartrates; but the results obtained with the acetates are somewhat uncertain, as it is difficult to procure these salts absolutely free from the empyreumatic products which accompany the acid as it is usually prepared. The *oxalates* have a low diactinic power.

But the group most remarkable for its absorptive action is formed by the *nitrates*. Nitric acid, whether dissolved in water or in combination with a metallic oxide, has a specific action in arresting the chemical rays: the more refrangible portion it transmits freely, and then intercepts the spectrum abruptly at the same point whatever base be united with the acid, provided the base be capable of forming diactinic salts. The *chlorates*, on the contrary, are strongly diactinic.

13. From the observations above detailed, it appears that the following acids may be considered as possessing high diactinic capacity,—viz. the sulphuric, hydrochloric, hydrofluoric, chloric, carbonic, and boracic acids. Inferior to these are hydrobromic, phosphoric, arsenic, tartaric, citric, acetic and oxalic, hydriodic, sulphurous and hyposulphurous acids, whilst nitric acid is still less diactinic. Chromic acid arrests all the chemical rays; and the presence of a tinge of yellow or green colour in any compound is immediately apparent in a great reduction in the amount of its diactinic power.

14. Among the bases, potash, soda, ammonia, baryta, lime, strontia, magnesia, and alumina are eminently diactinic. Oxides of zinc, mercury, and lead approach them in

* A specimen of sea-water which had been standing for some months in my laboratory, furnished a resul identical with that obtained by using a strong solution of pure chloride of sodium.

power; but coloured bases, like oxide of iron, nickel, cobalt, or copper, are very inferior; and when the salts which they form are green or yellow, they are nearly opaque.

It is remarkable that, notwithstanding the high diactinic quality of silica, none of the different varieties of glass transmit rays extending beyond one-fifth or one-sixth of the range afforded by quartz. This absorptive action is produced by a lamina of glass less than the one-hundredth of an inch in thickness, which cuts off the more refrangible rays nearly as completely as a piece of glass of twenty times the thickness. All glass apparatus must therefore be abandoned in these experiments, and apparatus of quartz substituted for them.

15. I had no encouragement in my attempts to construct prisms of other materials than rock-crystal. Rock-salt offers no advantage, and it is too soft and deliquescent to yield prisms or lenses comparable with those of quartz. I did indeed make a considerable number of experiments with a hollow prism furnished with thin quartz sides, and filled with water. But the refractive power of water is less than that of rock-crystal, and its dispersive power is not higher. The addition of pure chloride of sodium till the water is saturated does not materially increase the refractive or dispersive power, whilst it appeared (in a very slight degree it is true) to diminish the amount of the more refrangible rays, so that, on the whole, I found it more convenient to work with a quartz prism, the double refraction of which in the position in which I used it, was so slight that it was not a source of any inaccuracy of importance.

b. *Absorption by transmission through Liquids.*

16. In the experiments with liquids, the same plate-glass trough with quartz sides was used as when solutions were employed, and the apparatus was arranged in exactly the same manner. Great care was taken in the purification of each specimen. The *wood-spirit* was prepared from oxalate of methyl by Wöhler's method, and it, as well as the *alcohol* and *fousel oil* employed, was in the anhydrous state. The *glycerin* was perfectly colourless, and was prepared by Mr. Geo. Wilson by distillation with superheated steam; it retained about 4 per cent. of water. The specimen of *glycol* was the only one about which I had any doubt; it had a barely perceptible yellowish tinge, and a very slight empyreumatic odour. The *carbolic acid*, given me by Mr. Crace-Calvert, was a beautiful colourless specimen, which, by a slight reduction of temperature, solidified to a mass of delicate white needles. The *benzol* was a specimen prepared from benzoate of lime, purified by congelation at 32°, and carefully rectified. The *paraffin oil* was a perfectly limpid colourless specimen obtained from Rangoon petroleum; it had a specific gravity of 0·831, and boiled steadily at 360° F. The *bisulphide of carbon*, and indeed most of the other liquids, were rectified immediately before proceeding to experiment upon them.

The following Table contains a list of the liquids operated on, and the lengths of the different spectra, in terms of the scale already explained (par. 7). The compounds included in the following Table, with the exception of nitric and hydrochloric acids, are not simply solutions, but liquids to which a definite chemical formula may be assigned.

TABLE II.—Diactinic Power of Liquids.

Thickness of stratum 0·75 inch.

Name of substance.	Termination of spectrum.	Relative lengths of spectra.	Remarks.
Water	170·5	74·0	
Wood-spirit	116·5	20·0	With a faint impression of the rays about 156.
Alcohol	159·5	63·0	
Fousel Oil	116·5	20·0	
Glycol	107·5?	11·0?	Slight empyreumatic odour.
Glycerin	114·5	18·0	
Ether	112·5	16·0	
Chloroform	122·5	26·0	
Dutch Liquid	132·5	36·0	
Oxalic Ether	115·5	19·0	
Carbolic Acid	104·5	8·0	
Benzol ($C_{12}H_6$)	117·5	21·0	
Paraffin Oil, $n(C_nH_n)$	111·5	15·0	Specific gravity 0·831. Boiling-point 360°.
Oil of Turpentine	104·5	8·0	
Phosphorus (melted)	.....	0	Slight yellowish tinge.
Bisulphide of Carbon	102·5	6	
Oxychloride of Phosphorus	.....	0	
Terchloride of Phosphorus	.....	0	Retaining a little phosphorus in solution.
Terchloride of Arsenic	101·5	5·0	
Acetic Acid	112·5	16·0	Glacial.
Sulphuric Acid	160·5	64·0	
Nitric Acid	106·5	10·0	Specific gravity 1·3.
Hydrochloric Acid	152·5	56·0	Specific gravity 1·1.

The starting-point for each spectrum was 96·5 upon the scale already adopted.

Of all these liquids, water and alcohol are the only two, except sulphuric and hydrochloric acids, which are strongly diactinic; water is eminently so, alcohol in a much less degree. No relation in this respect is traceable between common alcohol and the other alcohols examined, viz., wood-spirit, fousel oil, glycol, glycerin, and the phenic alcohol carbolic acid. Bisulphide of carbon, the refractive medium employed in my earlier experiments, is singularly deficient in diactinic power, and is therefore eminently unfit for such researches.

c. *Absorption of Chemical Rays by transmission through Gases and Vapours.*

17. In the experiments upon the absorbent action of aëriform media, the gas or vapour under trial was introduced into a brass tube 2 feet long, blackened on the inside, and closed at the end by plates of quartz, which were fitted on so as to form air-tight joints. The tube could be attached by a stopcock to the plate of the air-pump, and after exhausting the air any gas could be easily introduced. In cases in which the gas was liable to act upon the metal, a glass tube was substituted for the metallic one, and the gas was introduced by displacement. The tube when prepared was interposed at *t*, fig. 1 (par. 6), between the slit *s* and the prism *b*, and the rays emanating from the electric spark were, after traversing the column of gas contained in the tube, received first upon the prism and lens, and then upon the excited collodion surface, in the usual manner.

When the vapour of a volatile liquid was to be examined, a few drops of it were generally allowed to fall into the tube filled with air, through which the vapour was allowed to diffuse itself at the ordinary temperature. The action of such vapours was therefore compared at a great disadvantage with that of the various gases, particularly where the volatility of the liquid was rather low. The results, however, even under these disadvantageous circumstances, were well marked, as may be seen by examining the subjoined Table of gases and vapours submitted to experiment, in which the comparative lengths of the different spectra are shown in the second column of figures.

TABLE III.—Absorbent action of Gases and Vapours on the Chemical Rays.

Length of column of gas 2 feet.

Name of gas.	Termination of spectrum.	Relative lengths of spectra.	Remarks.
Atmospheric Air	170·5	74·0	
Hydrogen	170·5	74·0	
Carbonic Acid	170·5	74·0	
Carbonic Oxide	170·5	74·0	
Olefiant Gas	162·5	66·0	
Marsh-gas	159·5	63·0	
Coal-gas	133·5	37·0	Cut off abruptly.
Protoxide of Nitrogen	159·5	63·0	
Cyanogen	159·5	63·0	
Ammonia	170·5	74·0	
Sulphurous Acid	110·5	14·0	Cut off abruptly.
Sulphuretted Hydrogen	110·5	14·0	Cut off abruptly.
Bisulphide of Carbon	101·5	6·0	A few of the strongest lines between 140 and 152 are seen.
Dichloride of Sulphur	108	10	
Benzol	131·5	35·0	Faint beyond 111·5.
Oil of Turpentine	152·0	55·5	
Chloroform	152·0	55·5	
Ether	163·5	67·0	
Terchloride of Phosphorus	131·5	35	Very feeble spectrum.
Oxychloride of Phosphorus	141·5	45	Fades out very gradually.
Hydrochloric Acid	151·5	55·0	
Hydrobromic Acid	119·5	23	Cut off abruptly.
Hydriodic Acid	111·5	15	Cut off abruptly.
Peroxide of Nitrogen	0	0	
Peroxide of Chlorine	0	0	

18. The absorbent action disclosed by the foregoing experiments on the colourless gases and vapours is very interesting, as it proves that differences exist in the diactinic power of these substances quite as marked as in the case of liquids and solids. Some of the *elementary* gases, oxygen, hydrogen, and nitrogen, appear to possess a diactinic capacity greater than any solid or liquid body. Many *compound* gases, such as ammonia, carbonic acid, and carbonic oxide, appear to rival them. Olefiant gas, cyanogen, and hydrochloric acid exhibit a decided but not great absorptive power, with which that of the vapours of ether, chloroform, and oil of turpentine at the atmospheric tension, and when diffused through air, may be compared. Doubtless if these vapours were tried at a tension of 30 inches, they would exhibit greater absorptive power. The absorptive

action of hydrobromic acid much exceeds that of the hydrochloric, and that of hydriodic acid is greater than of either.

The abrupt termination of the spectrum in coal-gas is remarkable. The absorption appears to be due not to the permanent gases, but to the vapours of benzol and other heavy hydrocarbons which it contains. The four compounds of sulphur, viz., sulphurous acid*, sulphuretted hydrogen, bisulphide of carbon, and dichloride of sulphur, are especially active in absorbing the chemical rays; and the vapours of the terchloride and oxychloride of phosphorus exhibit a similar though less intense absorptive power.

19. Coloured gases, whether elementary or compound, such as chlorine, bromine, and nitrous gas, have long been known to exert an absorptive action upon the luminous rays†; and their effect is not less marked upon the invisible prolongation of the electric spectrum.

The effects of the three halogens, chlorine, bromine, and iodine, in the form of vapour, are particularly remarkable. As a general rule, when a body exerts an absorptive influence the absorption is greatest in the most refrangible portions; but the reverse of this occurs in the case of chlorine and of bromine. A column of *chlorine* two feet in depth, cuts off the whole of the *less* refrangible portion as far as 143·5; beyond that a distinct impression is obtained as far as about 159. With *bromine* diffused in the form of diluted vapour, the impression commences at 106, and is continued distinct, though rather feeble, to the extreme end of the spectrum. The apparatus required a slight modification to adapt it for the experiment with *iodine*. I had a glass tube 6 inches long, the open ends of which were ground flat so as to admit of being closed by thin plates of quartz; this was enclosed in a brass tube; a few grains of iodine were introduced, and the quartz plates fixed by metallic caps perforated to admit the passage of the rays; this tube could then be supported as usual between the spark and the prism, and could be raised to and kept at a temperature beyond that necessary for the volatilization of the iodine. The electric light, after traversing such a column of vapour of an intensely deep violet colour, gave a strong spectrum, extending from 96·5 as far as 112, then it gradually faded till it disappeared at about 118; the impression became again rather faintly but distinctly visible at 142, and gradually disappeared at about 156. It is interesting to notice a somewhat similar interrupted absorption of the rays, though at a different part of the spectrum, in the case of the metallic iodides.

Both peroxide of nitrogen and peroxide of chlorine, in a stratum of 2 feet in depth, wholly absorb the chemical rays; but when more dilute or in shorter columns, they each give characteristic absorption-bands.

20. There appears to be little or no connexion between the absorptive power of any particular gas for the chemical rays, and its power of absorbing radiant heat as determined by the experiments of Dr. TYNDALL‡. Aqueous vapour is highly diactinic, though not diathermic; olefiant gas exhibits a similar difference; and various other instances might be pointed out.

* An aqueous solution of sulphurous acid cuts off the spectrum at the same point as the gas itself does.

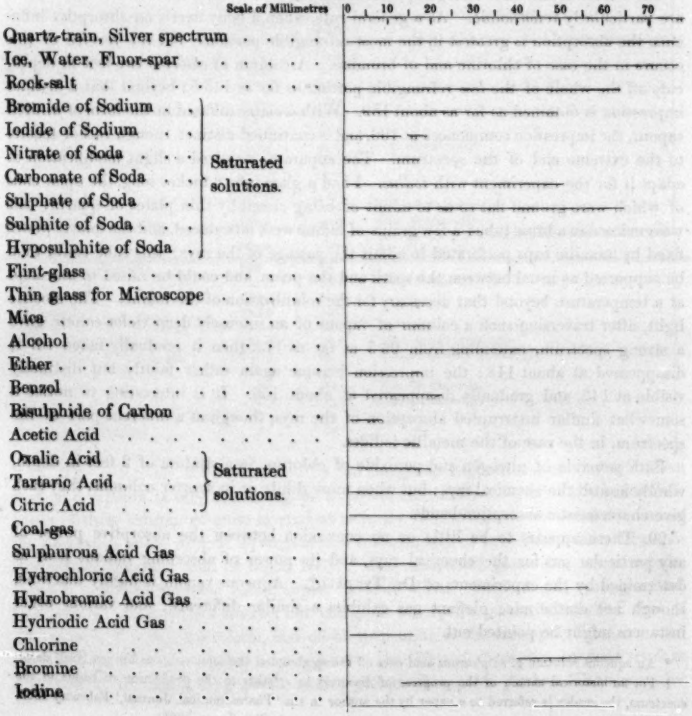
† For an historical sketch of the progress of discovery in relation to the production of bands in the spectrum, the reader is referred to a paper by the author in the 'Pharmaceutical Journal,' February 1862, p. 17 *et seq.*

‡ Phil. Trans. 1861.

21. The most interesting fact, however, disclosed by these various experiments is the persistence of either the diactinic or the absorbent property in the compound, whatever be its physical state—a circumstance which proves that the property under consideration is intimately connected with the atomic or chemical nature of the body, and not merely with its state of aggregation.

The following diagram represents approximatively the relative position of the portions of the spectrum transmitted in a few of the cases described in the foregoing section of this paper. No attempt is made to indicate partial absorption of the rays. In one or two instances, where complete absorption at a particular part of the spectrum occurs, this has been indicated by an interruption in the line.

Relative absorptive action of various Media upon the Electric Spectrum of Silver.



§ 2. THE ABSORPTION OF THE CHEMICAL RAYS BY REFLEXION FROM POLISHED SURFACES.

22. In my earlier experiments I had much difficulty in obtaining a spectrum all the parts of which were even approximatively in focus in the same plane, and, with the view of remedying this defect, I tried the effect of substituting specular reflexion for the refracting action of a lens. This led me to compare the reflecting-power of different polished surfaces for the chemical rays. With this object in view, a small polished plate of the material under experiment was supported at an angle of 45°, as shown in fig. 3 (par. 6), opposite the vertical slit of the apparatus, so that when the source of light *e*, was placed at right angles to the axis of the tube, the rays were reflected down the tube in the direction of that axis. The arrangement of the prism, lens, and camera was the same as that already described (6). As, however, much less light was reflected upon the prism from the polished surface than that which fell upon the prism when the direct rays of the spark were employed, the exposure of the sensitive plate in the camera was prolonged from 5 minutes to 10.

23. Among the metals and alloys thus submitted to trial were platinum, gold, silver, mercury, contained in a trough with quartz faces, lead, copper, tin, cadmium, zinc, aluminum, steel, brass, and speculum-metal. In addition to these, the reflecting-power of quartz, window-glass, and Iceland spar was also tried.

No judgment of the perfection of the reflecting-power could be formed from the colour of the metal. *Gold* possesses the power of reflecting all the rays, even the most refrangible, very equally, though somewhat feebly. Next to gold ranks burnished *lead*, some part of the spectrum of the electric spark reflected from lead being more intense than that from gold. The length of the spectrum obtained from the light of the electric spark between silver points, by reflexion from the surface of these two metals, extended from 96·5 to 170·5, or over the full distance of that obtained by the direct light of the spark, viz. 74 divisions of the scale which I have adopted. With all the other metals the spectrum of the same reflected spark terminated at 159·5, covering only 63 divisions of the scale.

The spectrum from a *silver* surface was remarkable. The impressed image was strong up to 112·5; then an abrupt cessation of the reflected rays occurred for a distance of 1·5 division; beyond this the reflexion gradually returned, and continued tolerably intense till it reached 159·5, covering 63 divisions of the scale.

The reflexion from *mercury* was weak in the middle, but strong towards each extremity. *Platinum*, *zinc*, and *aluminum* resembled mercury in their effects, but the spectrum was much less intense. The reflexion from *cadmium* was similar, but still weaker.

The spectrum of the rays reflected from *copper* was deficient in strength for the last half of the more refrangible portion; and that of *brass* was similar to it, but weaker. The reflexion from a surface of *steel* was more intense than that from any surface which I employed, but it ended abruptly at 159·5, or at the 63rd division of the scale. The spectrum reflected from *tin* was nearly as complete as that from steel.

A small concave mirror of *speculum-metal* gave an intense spectrum for the first half;

but the more refrangible portion was deficient in power, and no rays were reflected beyond 159·5 (63 divisions), the point at which the other metals also failed. I therefore abandoned the attempt to substitute a speculum for the lens, with which latter I succeeded subsequently in obtaining a field sufficiently flat for the purpose.

24. The reflexion from the surface of transparent objects was so scanty that, of course, no idea was entertained of using such bodies as mirrors; but it may be worthy of notice that a feeble spectrum was obtained from surfaces of *quartz*, *window-glass*, and *Iceland spar* extending to 159·5, or over a length of 63 divisions of the scale—that is to say, fully as far as the majority of the metals. The quantity of the reflected rays was small, but its quality was similar to that of the rays reflected from metallic surfaces.

§ 3. PHOTOGRAPHIC EFFECTS OF THE ELECTRIC SPECTRA OF DIFFERENT METALS TAKEN IN AIR.

a. *Pure Metals.*

25. I have spent a considerable time in endeavouring to procure exact photographs of these spectra, inasmuch as the spectrum of a metal is a constant not less important than its density or its fusing-point; and it frequently furnishes the means of identifying an element under circumstances in which no other method at present known is practicable.

Kirchhoff, in his elaborate and masterly researches on the constitution of the solar spectrum, has, as is well known, published in minute detail a map including the lines of a large number of the metals. He has, through a limited portion of the visible spectrum, laid down the position of the bright lines of certain metals coincident with particular dark lines of Fraunhofer, with a precision best appreciated by those who have followed him with most minuteness.

Much yet, however, remains to be done even for the rays which fall within the range of the visible spectrum; and for those which are beyond the limits of ordinary vision, the whole yet remains to be examined.

The lines of each spectrum are so numerous and so close together, that it would be impossible without a sacrifice of time, that would scarcely be justifiable, to obtain accurate impressions of them by eye-drawing. Indeed, except by the process of photography, these lines can only be rendered visible by the aid of a fluorescent screen, under which circumstances the minute details are almost necessarily lost even by the most careful observer.

The photographs of these spectra were obtained by an arrangement of the quartz prism and lens, identical with that already described (6), wires, plates, or irregular fragments of the metal, according to circumstances, being supported in brass forceps connected with the secondary wires of the induction-coil. The interval traversed by the spark was in each case about a quarter of an inch, and the slit was placed at a distance of half an inch from the line traversed by the spark.

The specimens of gold, silver, mercury, copper, bismuth, antimony, zinc, tellurium, thallium, and lithium employed are believed to have been pure. The tungsten,

molybdenum, chromium, and manganese were reduced from pure oxides in crucibles lined with charcoal. The other metals were as they are furnished in commerce as pure.

26. Each metal gives its own distinctive spectrum; but it is remarkable that these differences are not obvious in the less refrangible end. The true metallic spectrum, when the sparks pass in air, is in fact combined with that due to atmospheric air, as has already been pointed out for the visible rays by Ångström and by Alter. The photographic lines of the air-spectrum are most marked in the less refrangible portion, whilst the characteristic lines of the metals are particularly evident in the more refrangible parts. Hence the photographs which I formerly obtained by the use of a prism of bisulphide of carbon, which transmits rays of low refrangibility only, represent, as I then correctly pointed out, lines which are chiefly atmospheric; and consequently they exhibit appearances which are almost identical whatever be the metal employed.

In describing the spectra of the different metals, I shall employ the same arbitrary scale that I have hitherto used in this paper.

27. It will be observed that generally the lines as they advance towards the less refrangible extremity become less intense in their central portion, until towards the extreme limit of the spectrum, the two marginal ends of the lines alone are visible, though these terminations are often rather intense. Indeed, throughout the whole length of the impressed photograph, the marginal extremities of the metallic lines leave a stronger image than their central portions, as though the incandescence of the volatilized portions of the electrodes, owing to their high radiating power, did not continue sufficiently intense during their transfer across the interval between the two electrodes, to enable them to produce a continuous line. Evidently the cause of this diminution of action operates more powerfully upon the more refrangible rays; and a higher temperature, as the experiments of other observers have abundantly proved, is necessary to the production of radiations of these high degrees of refrangibility.

Exceptions to this remark occur in the lines due to the atmosphere; this is well seen in the strong line at 110·5, which is in marked contrast to some of the metallic lines in its vicinity, particularly in the spectrum of silver (Plate XXXIX. fig. 9), where this nitrogen-line is included between two pairs of very intense lines due to the metal itself, and which are each interrupted in the middle.

In order to abbreviate the description of the various spectra, I shall generally speak of these interrupted lines as "*dots*"; they, indeed, constitute the characteristic features of the different metallic spectra. These dots, if the image be exactly in focus, may usually be seen to consist of groups of very short lines closely aggregated. This is well shown in some parts of Plate XL. fig. 39, which represents the spectrum of silver; and it is less distinctly shown in the spectra of palladium (fig. 38), of copper (fig. 40), of antimony (fig. 41), and of cadmium (fig. 42). These spectra were taken with the screen, lens, and prism at a distance from the slit different from those with which the other impressions were procured; some parts are consequently out of focus, but the details of other portions are shown more fully.

As might be anticipated, the spectra of the more volatile metals are the most intense—those of bismuth and antimony, of cadmium, zinc, and magnesium being especially remarkable in this respect.

A certain similarity is also observable in the spectra of allied metals, as in the case of the three metals last mentioned, also in those of iron, cobalt, and nickel, of bismuth and antimony, as well as of chromium and manganese.

It should further be observed that, in estimating the apparent length of the different spectra, considerable difficulty is frequently experienced owing to the extremely faint impressions which the most refrangible rays commonly occasion; in some experiments this portion of the spectrum with the same metal appears to be longer than in others made under apparently similar conditions.

28. *Platinum.*—The characters of the spectrum of platinum are feebly marked. The *atmospheric lines* are well developed. It is important to remark that the *continuous spectrum* which forms the background to all the metallic spectra in their less refrangible portion, appears to be due to the oxygen and nitrogen of the atmosphere. Between 96·5 and 103·6 this spectrum is intense, and is crossed by a strong pair of compound lines followed by three strong groups of lines, ending in two other groups, each successively of less intensity than the preceding ones. At 107·5 is a well-defined line, and a strong band at 110·5. Three others, nearly equidistant, follow at 114, 117·3, and 121·7: at 137 and 138·2 are two faint lines, and beyond these, at 142·5, is a very faint pair of lines. All these are atmospheric lines. The true metallic spectrum of platinum (Plate XXXIX. fig. 5) gradually fades out with a series of groups of dots, and terminates at about 162.

29. *Iridium.*—The spectrum of this metal, for a fine sample of which I am indebted to my friend Professor Wheatstone, scarcely differs sensibly from that of platinum. The lines apparently most prominent are atmospheric. (See Plate XL. fig. 44.)

30. *Palladium.*—This spectrum is much more uniform in intensity than that of platinum. Besides the usual atmospheric lines, groups of dots commence at 103·5, and continue at irregular intervals. Four of the strongest of these groups occur at 138·5, 143, 148, and 152·5, measuring at about the centre of each group. The spectrum terminates rather abruptly at about 162·5. (Plate XXXIX. fig. 6, & Plate XL. fig. 38.)

31. *Gold.*—The spectrum of this metal has about the same degree of intensity as that of palladium, and it is almost exactly equal to it in length. Amongst its numerous lines, the most characteristic are two pairs of dots very close together at 124, and three groups of dots, commencing at 130·0, 143·5, and 153·5 respectively; the last is faint. (Plate XXXIX. fig. 7.)

32. *Silver.*—The spectrum of this metal is very characteristic. It is intense for the first third of its length, then becomes much fainter, after which several remarkable and very strong groups of lines are observed, beyond which the impression disappears at 170·5. The most conspicuous lines are a pair of double lines interrupted in the middle groups of dots rather strong, at 126·8, 129·0, and 131·0; between 140·5 and 144·5 are three very strong groups of dots. About 148 is another broad strong group; beyond

which, and terminating at about 159·5, is another strong triple group of dots,—the spectrum terminating at 170·5, with six nearly equidistant but rather faint groups of dots*. (Plate XXXIX. fig. 9, & Plate XL. fig. 39.)

The strongly marked character of the spectrum of silver, and particularly the renewal of its intensity towards the more refrangible end, rendered it very appropriate for the purpose of testing the diactinic quality of different media; and accordingly I have used it more extensively than any other metal in the experiments already detailed upon this subject.

[33. *Thallium.*—The spectrum of thallium (for a specimen of which in a pure state I am indebted to the kindness of Mr. CROOKES, its discoverer) is particularly interesting, as in its visible portion it is remarkably simple, the single intense green line being the only one visible, even when heated in the intense flame of the oxyhydrogen jet. When, however, the sparks of the secondary coil are transmitted, not only do new lines make their appearance in the visible spectrum, but also in the extra-violet portion, and the complex impression shown at Plate XL. fig. 45 is developed. This character of its spectrum† separates thallium from the metals of the alkalies. In the less refrangible portion are two strong groups of lines at about 103 and 106; three other groups occur at 116, 121, and 126 respectively, the two first less intense, the third of about the same strength as the first pair of groups. Several feebler pairs of dots follow; and the spectrum terminates with four nearly equidistant groups, commencing respectively at 136, 141, 145, and 151: the first of these groups is very strongly marked, the others are fainter but of nearly equal intensity.—Feb. 1863.]

34. *Mercury.*—Experiments were made with this metal by soldering a platinum wire into a small glass tube which was filled with mercury and connected by means of the platinum wire with one end of the secondary wire of the coil; the other electrode consisted of a platinum wire. The spectrum obtained exhibited few lines, excepting those due to the mercurial electrode. The never-failing nitrogen line, 110·5, was evident; but there were numerous strong lines due to the mercury, the most distinct of which are those at 104, 114·5, 117·5, 119·0, 122·5, 131·0, 138, 156, 159, each of the two last forming a strong broad group of dots, the last group terminating the spectrum at 161·0. (Plate XXXIX. fig. 10.)

35. *Lead.*—This spectrum is very strong for rather more than one-third of its length; it then diminishes in strength, until the action ceases almost entirely at 146·5; at about 161 it is renewed abruptly by a strong group of dots, which terminate the spectrum at 162·5. The lines in this spectrum are numerous and complicated. It exhibits an at 109·5 and 111·5, equidistant from the nitrogen line 110·5; beyond this are three intense triple group of dots between 122 and 125, and two other strong groups at about 130 and 132. (Plate XXXIX. fig. 11.)

* In one or two instances, when using bromiodized collodion, I saw a very faint series of groups prolonged as far as 190·0.

† Proceedings of the Royal Society, January 1863, vol. xii. p. 407.

36. *Copper.*—The spectrum of this metal is considerably prolonged. The intensity of the light from copper points is liable to vary considerably during the course of an experiment, being apparently much influenced by the slight changes of form experienced by the electrodes in consequence of the action of the discharge upon them. In these experiments I always used thin sheets of electrotype copper. The most marked lines in the spectrum of copper are the following: viz., two close together at 111·7 and 112·3; these are followed by three strong nearly equidistant groups of dots at 128, 136·5, and 146·7; a very strong group appears at 156·7; and the spectrum ends at about 181·5, with a series of much fainter groups. (Plate XXXIX. fig. 12, & Plate XL. fig. 40.)

37. *Tin.*—The spectrum of this metal shows at 107·0 and 112·5 a pair of strong double dots, at 114 another dotted line, at 118·0 a strong double line; characteristic groups of dots commence at about 122·0 and 129·5; between 130 and 134 it exhibits three strong groups, followed by several well-marked pairs of dots to about 154, after which it terminates rather abruptly by four nearly equidistant faint groups at about 163. (Fig. 13.)

38. *Bismuth.*—This metal furnishes a strong and well-marked spectrum. Five pairs of dots show themselves between the line H and the nitrogen line 111·5; a strong pair is then seen at 115·3, followed by five strong groups, each of which is triple; the first of these is the most intense; these are followed by an intense group, which terminates at 122·0; beyond these the spectrum is continued by a numerous and intense series of groups of dots, particularly at 143 and 157, and terminates at about 158. (Fig. 14.)

39. *Antimony.*—The spectrum of antimony is also very characteristic. A triple series of groups of dotted lines commences at about 104·5; the nitrogen line at 110·5 is very intense; at 113 is a strong double line followed by seven or eight intense groups of dots which terminate at about 138·5; at 150·5 is a group of moderate intensity; and the last traces of lines disappear at about 164·0. (Figs. 15 & 41.)

40. *Arsenic.*—The characteristic dotted lines of this spectrum commence at 115·0; a series of groups occur very close together, ending at about 129·0; then follow six fainter irregular groups; and the spectrum terminates abruptly with three very strong groups—the first two of which nearly run into each other, succeeded by an interval, the last group ending at 155. (Fig. 16.)

41. *Tellurium.*—This spectrum is highly characteristic. It exhibits a close series of dots, commencing at about 106, and terminating by a very strong group at 147·5. There is then a complete blank, till at 156 another group is seen, then an interval, and the spectrum terminates abruptly with a well-defined group at 168·5. (Fig. 17.)

42. *Tungsten.*—This spectrum is not very intense. It shows a double dotted line at 114, and a stronger one at 125; it is prolonged by a distinct series of dots to about 145, and fades out at about 168. (Fig. 19.)

43. *Molybdenum.*—The spectrum of this metal resembles that of tungsten, but is more intense. It is prolonged by a very faint termination to about 157. (Fig. 20.)

44. *Chromium* shows a group of dots at 106·0, then a strong line at 114·5, then

three intense groups of dots between 122 and 131, beyond which it gradually fades till it is lost at 160·0. (Fig. 21.)

45. *Manganese.*—This spectrum is well-marked. A double group of dots appears at 107, then five strong groups of dots and lines between 119·4 and 135·5; the first is the most intense, and the last group is broad and complicated: beyond this the impression becomes gradually fainter, and disappears at about 152·0. (Fig. 22.)

46. *Iron.*—The spectrum of iron is intense, particularly in the more refrangible portion. Between 113 and 124 are three diffused groups of dots of moderate intensity; at 126 is a very intense group; then a series of numerous intense groups of dots, which terminate at 154; at 155·5 a series of fainter groups recommences, and fades away at about 162. (Fig. 23.)

47. *Cobalt.*—The spectrum of cobalt is very like that of iron in its general appearance; but it shows two or three rather strong groups of lines between 106 and 109; an increase of intensity commences at about 128, and is continued in a series of groups of very strong dots, the most intense of which are situated between 134 and 147: the spectrum terminates rather suddenly at about 163. (Fig. 24.)

48. *Nickel.*—This spectrum is not so intense as either that of iron or of cobalt, but it is like them in its intensity being greater near the more refrangible extremity (fig. 25). It is a very long one, extending to about 190, and exhibits an arrangement of groups of dots at its more refrangible end, resembling that of silver, but prolonged much further.

49. *Cadmium.*—This is a striking spectrum. The action is accumulated into intense bands with perfectly dark intervals. Two broad strong groups of lines occur at 105 and 107, then two other compound bands or groups of dots, one on each side of the nitrogen line 110·5; beyond this are two fainter lines, then at 118 and 121 two broad groups of dots, frequently prolonged into lines; at 126·3 a very strong group of dots, and another at 133·5; beyond this an almost entire cessation of action till it is resumed by three groups of dots, the first and last of which are the strongest in the entire spectrum. These groups commence at 149·5 and terminate at 155·5; beyond these are two other detached groups at 162·5 and 167, where the spectrum terminates abruptly. (Figs. 26 & 42.)

50. *Zinc.*—This spectrum is equally characteristic with that of cadmium. Between 109·5 and 112·5 is an intense double group of eight or nine distinct lines, then several well-marked lines in the interval between these and another double group, which commences at 125. An interval of diminished action follows; and then between 135 and 140 are two intense groups, the strongest in the spectrum. These are followed by a few feeble groups of dots, after which is a complete interval; and the spectrum terminates with four groups of equidistant lines, the first commencing at 167·5, the latest terminating at 183. (Fig. 27.)

51. *Magnesium.*—This is another remarkable spectrum. An intense group of lines commences at 101; at 115 a bright group of dots is seen, and between 119 and 126·5 are three remarkably intense groups of lines: the first of these comprises at least four strong

lines, the second group three, and the third consists of eight or ten separate lines. This last is the most intense group that I have met with in the course of these experiments. Beyond this the spectrum is prolonged by a faint tail, which is strongest along the edges, and nearly vanishes midway between them; this tail disappears a little beyond 150. (Fig. 28.)

52. *Aluminum.*—This spectrum exhibits a characteristic group of dots at 106, another at 115·5, followed by others at irregular intervals as far as 155, beyond which no impression is visible. I have frequently repeated this experiment, as Professor STOKES informs me he that sees in the spectrum of aluminum lines which are beyond the limit of the zinc-spectrum, when the aluminum-spectrum is received upon a screen of uranium glass, or of a particular phosphate of uranium; but either the collodion plate is insensitive to rays of this extreme refrangibility, or, as I believe, the quartz prism which I employ begins to fail in transparency at about the end of the zinc-spectrum. (Fig. 29.)

53. *Sodium.*—The lines exhibited when sodium is employed appear to be mainly atmospheric; the usual nitrogen line at 110·5 is, however, developed into a broad band or group of nine or ten distinct lines, and the other atmospheric lines are very well marked; the spectrum is prolonged into a faint nearly continuous band at about 156, when it ceases to be visible. (Plate XL. fig. 47.)

54. *Potassium.*—The spectrum produced by potassium presents the same appearances as that of sodium, both being apparently only atmospheric (fig. 46).

[55. *Lithium.*—The spectrum of this metal differs from those of the other alkali-metals in presenting a single well-marked group of dots at about 123; it is prolonged into a tail, which resembles that of magnesium, and fades out at about 150. (Fig. 48.)—Feb. 1863.]

56. It is unnecessary to give any details of experiments made with electrodes one of which consisted of one metal and the other of a different metal. Under these circumstances the lines starting from the side corresponding to each metal are identical with those furnished by the particular metal. This mode of making the experiment is therefore frequently convenient when it is desirable to compare the spectrum of any given metal with another selected for comparison. When the difference in volatility between the two is extreme, as when platinum is opposed to mercury (fig. 10), it may happen that one spectrum only is seen, the lines starting from an edge of the photographic impression, and terminating at irregular distances before they reach the opposite edge.

b. *Spectra of Alloys.*

57. The principal object of these experiments was to determine the influence which small amounts of foreign metals exercise upon the photographic image. When equal weights of the two metals are employed (tin and lead, for example, or cadmium and lead), a compound spectrum exhibiting the lines due to both metals is produced; and it is not always the more volatile metal that predominates. An alloy containing 62 parts

of copper and 38 of zinc, gave a spectrum in which the lines due to copper predominated considerably. In an alloy of about 2 parts of zinc to 1 of cadmium the zinc-spectrum was the most strongly marked.

In another experiment an alloy of 990 parts of fine gold and 10 of fine silver was prepared; on taking the spectrum obtained by an exposure of 10 minutes, a distinct but feeble impression of the more refrangible lines due to silver was procured (see fig. 8). A contamination of gold with silver to an extent not exceeding 1 per cent. could therefore be recognized by this means; but prolonged exposure was necessary in order to develope the lines due to silver. An analogous result was obtained when the spectrum of plumbago was taken. In this case, in addition to the atmospheric lines, the spectrum of iron was distinctly impressed: the total amount of metallic iron in the plumbago was 3·94 per cent. Graphite deposited in the gas-retorts, which contained 0·23 per cent. of iron, gave very feeble indications of iron. On the other hand, no indication of iron was observable in the spectrum of brass which contained 0·23 per cent. of iron, nor was lead indicated in brass which contained 0·7 per cent. of this metal.

58. All the foregoing spectra were obtained either from the metals in their uncombined form, or else from their alloys. The electric spectra of a few other metals which admit of being submitted to experiment in their isolated form, still remain to be added. A considerable proportion of the metallic elements, however, are not included in the foregoing list. These it is almost impossible to examine, except in the form of some of their saline or other compounds. As, however, this portion of the inquiry is attended with some peculiar difficulties, I shall defer what I have to add upon this subdivision of the subject to a future occasion.

§ 4. PHOTOGRAPHIC EFFECTS OF ELECTRIC SPECTRA OF DIFFERENT METALS PRODUCED BY TRANSMITTING THE SPARKS THROUGH GASES OTHER THAN ATMOSPHERIC AIR.

59. In making experiments upon the influence of various gases upon the spectra of the electric spark, the arrangement of the apparatus was modified in the following manner:—The position of the slit, prism, lens, and camera was the same as in the preceding experiments (6); but the metallic electrodes were enclosed in a stout glass tube, shown at half its real size in Plate XL. fig. 49. *a* is the tube itself, *b* a hole drilled through the side of the tube, which upon this side is ground flat in order that it may be closed air-tight by the thin plate of polished quartz *c*. This plate is kept in its place by means of an elastic band. *d*, *d* are brass forceps screwed into the brass plugs *e*, *e*, for holding the electrodes. The ends of the tube are closed by the brass plugs *e*, *e*, which are ground to fit the ends of the tube, and are pierced by small brass tubes for the conveyance of the gas. An elastic band, passing from one end of the glass tube to the other, keeps the brass plugs in their place. The tube is then connected with a gas-holder

filled with the gas under experiment (or, when practicable, the gas is disengaged during the experiment), and, after the apparatus has been connected with the induction-coil and adjusted in its proper position, a slow current of the gas at the atmospheric pressure is transmitted, the excess of gas as it passes out of the apparatus being conveyed into the chimney or out of the window by a suitable arrangement of tubes.

A simpler apparatus was admissible when the wires could, like those of platinum or of iron, be soldered into glass. Fig. 50 shows this modification. A piece of tubing *a*, about an inch and a half long and half an inch in internal diameter, is united at each extremity to a piece of quill tubing *e*, *e*; the wires *d*, *d* are then soldered through its sides. A portion of the wide tube is ground away as at *b*, leaving an opening to which the quartz plate *c* can be applied, and kept in its place by small rings of caoutchouc. The gas was transmitted through the tube as in the other form of apparatus.

60. In one or other of these modes the following gases were submitted to experiment:—hydrogen, carbonic acid, carbonic oxide, olefiant gas, marsh-gas, cyanogen, sulphurous acid, sulphuretted hydrogen, ammonia, protoxide of nitrogen, nitrogen, oxygen, chlorine, and hydrochloric acid.

The general results of these experiments on the invisible rays are in harmony with those already obtained for the visible ones by MM. Ångström*, Alter†, and Plücker‡. The conclusions at which I have arrived may be thus summed up:—

1. Each gas tinges the spark of a characteristic colour; but no judgment can be formed from this colour of the kind of spectrum which the gas will furnish.

2. In most cases, in addition to the lines peculiar to the metal used as electrodes, new and special lines characteristic of the gas, if elementary, or of its constituents, if compound, are produced. When compound gases are employed, the special lines produced are not due to the compound as a whole, but to its constituents.

3. The lines due to the gaseous medium are continuous, not interrupted or broken into dots.

61. *Hydrogen.*—The spectrum of the spark taken in this gas is not characterized by any new lines. The most remarkable effect is the disappearance of the atmospheric lines, together with the great lowering of the photographic intensity, whether the metal employed be platinum, gold, silver, copper, iron, or zinc. It is interesting to observe that the characteristic lines of highly oxidizable metals, such as iron and zinc, are visible in hydrogen, though the impression on the plate throughout is very greatly reduced in intensity

62. *Carbonic Acid* and *Carbonic Oxide.*—The lines contained in the spectra of these two gases are identical; new lines characteristic of carbon occur in addition to the lines due to the nature of the metallic electrodes. The same lines are visible when other compounds of carbon, such as olefiant gas, marsh-gas, and cyanogen, are employed. The

* Poggendorff's Annalen, 1855, Bd. xciv. S. 141. † Silliman's Journal, 1855, vol. xix. p. 213.
‡ Poggendorff's Annalen, 1859, Bd. cvii. S. 497.

most characteristic lines in the spectrum of carbon are the following:—At 123 a strong line, a weaker one at 127, two strong compound lines at 138 and 140, and an intense compound line at 153.

With carbonic acid the special spectrum of silver appears much intensified. Some of the lines which appeared as dots in air are continued across the spectrum in carbonic acid. In carbonic oxide the intensity of the spectrum is less than in air; and this contrast between the two gases may be observed whatever be the nature of the metallic electrodes.

Fig. 35 exhibits the spectrum obtained between platinum points in carbonic acid. Fig. 36 shows the spectrum from gold points in carbonic oxide. Unfortunately in the Plate the figure is given a little too much to the right of its true position for accurate comparison with the spectrum above it; but the principal lines will at once be recognized as coinciding, if allowance be made for this displacement.

63. *Olefiant Gas.*—Some difficulty is experienced in observing the spectrum of this gas, owing to the copious deposition of carbon which occurs immediately that a current of sparks is transmitted. The nature of the electrodes employed seems to exert considerable influence upon this decomposition. It is extremely intense when aluminum electrodes are used, but comparatively slight with gold. Observations made when gold electrodes were employed exhibited a spectrum which could not be distinguished from that of carbonic acid or of carbonic oxide.

64. *Marsh-gas.*—Sparks pass freely in this gas. The spectra obtained with gold and copper electrodes cannot be distinguished from those of the same metals in carbonic acid and carbonic oxide. A scanty separation of carbon occurs during the passage of the spark. This is particularly evident when copper electrodes are used, the bluish light of the metallic spark being frequently accompanied by reddish yellow scintillations: the deposition of finely divided carbon upon the quartz plate on the side of the gas-tube impairs the intensity of the photograph.

65. *Cyanogen.*—A difficulty was experienced in this case also in obtaining intense photographs, particularly when silver electrodes were employed; a rapid deposition of a brown matter, probably paracyanogen, took place upon the interior of the tube. When copper electrodes were used, the light of the spark was sometimes of an intense green, at others of a pale blue. The photograph showed the particular lines due to carbon as well as those of nitrogen, and the special lines due to the metallic electrode employed.

66. *Sulphurous Acid.*—This gas offers unusual resistance to the passage of the electric sparks, the electrodes requiring to be brought very close to each other before the disruptive discharge passed freely. This difference in the power of different gases to modify the striking-distance has already been examined by Dr. Faraday*. A strong spectrum was obtained with gold wires: it terminated abruptly at 113·5, a single spot of renewed action appearing at 143·0. This result is due no doubt to the absorbent action of the gas, which has been already shown in a former section of this paper (18) to be one of the least diactinic of gaseous bodies. In this form of experiment the stratum

* Philosophical Transactions, 1838, p. 108.

of gas traversed by the rays before they entered the air amounted to about half an inch in thickness.

67. *Sulphuretted Hydrogen.*—This gas also offers considerable resistance to the passage of the electric spark. It is decomposed by the spark with deposition of sulphur. When gold electrodes are used, it furnishes lines resembling those of the same metal in air. With silver electrodes the gas was decomposed very rapidly, and no lines were produced beyond 113·5, the absorbent action of the gas being strongly manifested.

68. *Ammonia.*—Sparks pass in this gas as freely as in air; the spectrum of each metal is the same as in nitrogen; no new lines are visible in the photograph. Most of the atmospheric lines are distinct.

69. *Protoxide of Nitrogen.*—The electric sparks pass in this gas with much greater difficulty than in air. The spectrum appears to be the same as that produced in air, and no new lines are apparent in the photograph.

70. *Nitrogen.*—The spectrum of this gas, when gold or platinum electrodes are used, commences with a pale continuous spectrum, which slowly diminishes in intensity; this continuous spectrum appears to increase in intensity with the volatility of the metal, being well-marked in the case of magnesium, sodium, and potassium: at about 151 it terminates abruptly. The spectrum of nitrogen is crossed between 96·5 and 100 by two strong double lines; it shows an indistinct line at 108·5, a strong one at 110·5, three feeble lines at 113·5, 118, and 122, a faint band at 138, and another at 150. Fig. 33 shows the lines obtained from platinum points in nitrogen.

71. *Oxygen.*—This gas was obtained from black oxide of manganese heated with sulphuric acid. It gave, after purification by passing through a solution of caustic soda, lines identical with many of those obtained in atmospheric air. When the gas contained traces of carbonic acid, the lines due to the compounds of carbon were distinctly visible in the impressed spectrum. With platinum electrodes and with pure oxygen a feeble, nearly continuous spectrum extends to about 122·5; it also contains numerous lines extending as far as 142·5; beyond that, the impression is more feeble, terminating at about 156. The principal lines due to the gas are the following:—A broad line about 100, then two faint lines, beyond which, at 101·5, is a double line; a strong complex group at 103·5; a feebler one at 105·5; one rather stronger at 107·5; a double group of considerable strength at 112; another stronger at 114; between 116 and 119 is a group of six rather faint lines; after this there are no prominent lines until 138·2 and 141·5; at 153 is a strong compound line, and beyond this only the dotted lines of platinum are seen. (Fig. 32.)

72. *Chlorine* and *Hydrochloric Acid* give spectra which can scarcely be distinguished one from the other. With platinum points these spectra terminate by an abrupt band at 156·5. Their most marked features are a strong compound band at 96·5, and one still more marked at 100; then two lines, of which the first at 103 is the stronger, followed by two others, of which the second at 108·5 is the stronger: several fainter lines follow these lines. A group of six between 126 and 133, the most marked of which is a broad

band terminating at about 130. Several faint lines intervene between this and another broad band at 140, followed by several others less distinctly defined. (Fig. 34.)

I attempted to obtain the spectra of iodine and bromine by employing a current of hydriodic and hydrobromic acid; but the results were not satisfactory. It is very difficult to maintain a steady current of sparks through these gases, and not easy to keep up a continuous current of the pure and dry gases, which are immediately decomposed by the passage of the electric spark, with extrication of dense fumes of iodine or of bromine.

XXXV. *Further Observations on the Distribution of Nerves to the Elementary Fibres of Striped Muscle.* By LIONEL S. BEALE, *M.B., F.R.S., Professor of Physiology and of General and Morbid Anatomy in King's College, London; Physician to King's College Hospital.*

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THERE are two views with regard to the peripheral distribution of nerves, which are quite incompatible with each other. According to one, it is supposed that nerves end in the tissues to which they are distributed, by free extremities; while the other doctrine is, that free ends or extremities do not exist, and it is supposed that the fibre, after perhaps a very long and circuitous course, is connected with the nervous centre from which it emanated. If this be so, every nerve-cell, central and peripheral, must have at least two fibres proceding from it, must be bipolar or multipolar. Both these views cannot possibly be true.

That nerves terminate in ends or free extremities is the opinion of many Continental observers, and of late years this view, it may almost be said, has been generally received by anatomists.

The loops and plexuses described by the older observers have since been proved not to be *terminal*. Some of the fibres forming what appears to be a loop, have been seen to divide into finer branches, and these, after having been traced for some distance, become very thin, and are gradually lost. This change occurs abruptly in some situations, but in others a more gradual attenuation is observed.

In some tissues pale fibres have been traced a short distance beyond what appears to be the end of the dark-bordered fibres. But, it will be shown, the dark-bordered fibres differ so very much in diameter, that some of the thinnest are so very fine as scarcely to be distinguishable with very high powers, and in parts they very closely resemble some of the so-called pale fibres. In young animals the fibres corresponding to the dark-bordered fibres closely resemble the pale fibres of fully formed animals. In no tissue has it been more confidently stated that nerves terminate in free ends than in voluntary muscle; and although some differences of opinion exist as to the precise manner in which the nerves end, the existence of these ends is supported by the testimony of so many observers, that it is now almost regarded as an anatomical fact which is settled beyond question.

Yet it may be said that, as plexuses, loops, and networks * of very fine fibres in young

* In using the term network, I do not mean to imply that fine nerve-fibres unite with each other after the manner of capillaries, but merely that the *bundles* of fibres are arranged like networks. The fibres composing the bundles do not anastomose. In lace the appearance of a network of fibres is produced; but

tissues are represented by networks and plexuses of coarser fibres in adult tissues, and as plexuses of coarse and fine fibres may be seen in the adult tissues at all periods of life, it is only reasonable to assume the existence of networks composed of fibres so very fine as scarcely to be visible by the highest powers we possess, and so delicate as to be destroyed by the most careful manipulation, or to become disintegrated almost immediately after the death of the animal. All argument, however, must give way to observation; and even if the results of observation are incompatible with conclusions previously regarded as true, the new facts must be received, and our inferences must be modified accordingly. But, on the other hand, it will be admitted, in an anatomical inquiry like the present, that there may be the greatest difference of opinion as to the actual demonstration. The *ends* which one observer may consider to be natural terminations, by another may be held to be merely *apparent ends*, depending upon our being unable to see the continuation of the fibre in consequence of its extreme tenuity. The importance which all observers attach to the process of preparation they follow, is alone sufficient to show that the appearances produced are very different according to the manner in which a specimen is examined; and further, it is quite certain that many points to be readily demonstrated by one process, are quite invisible when another plan is followed. This is one explanation of the many conflicting statements as to facts of observation.

In a paper published in the Philosophical Transactions for 1860, I was led to conclude that many of the so-called connective-tissue corpuscles observed upon the muscular fibres were connected by very delicate granular fibres nearly as wide as the corpuscles, but only to be seen in specimens preserved in fluids which refracted very highly; and I also satisfied myself that these fibres were continuous with the nerve-fibres; and I stated that the nerve-fibres ramified with the capillaries external to the sarcolemma. My conclusions were terribly at variance with those of other observers; for not only was I compelled to infer (1) that the nerve-fibres formed, as it were, a network over the muscular fibres, but (2) that every muscular fibre was supplied with nerves throughout its entire length. It is usually maintained, 1st, that nerve-fibres terminate in free ends on the muscle; 2nd, that nerve-fibres only come into contact with the muscular fibre at very distant points: so that while the fibre, or the entire muscle, is freely supplied with nerves at one situation, the greater part is altogether destitute of nervous supply.

The Views of KÜHNE *and* KÖLLIKER.

Since my paper was published, an elaborate memoir on the 'Peripheral Organs at the ends of the Motor Nerves' has been written by KÜHNE; and the same inquiry formed the subject of the Croonian Lecture delivered a month since by Professor KÖLLIKER.

The conclusions of both observers are quite opposed to my own. KÜHNE and KÖLLIKER

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every apparent thread is composed of several, each of which pursues a complicated course, and forms but very small portion of the boundary of any one single space. In Plate XLI. fig. 5 a nervous network exists but each cord is compound, and composed of numerous fibres which never anastomose.

agree as to the existence of free ends. The former maintains that these are situated beneath the sarcolemma, and are connected with peculiar organs; the latter, that the free ends lie upon the surface of the sarcolemma. KÖLLIKER has failed to demonstrate the special organs described by KÜHNE. Both observers agree that the muscular fibre receives but a limited supply of nerves, and that the supply is limited to one part of the muscle.

As these observers have worked upon the muscles of the frog, I shall restrict myself entirely to the consideration of the distribution of the nerves to the muscles of this animal, and mainly to the particular muscle which these and most German observers have studied, viz. the thin pectoral muscle.

In many of KÜHNE'S drawings a pale band as broad as (or broader than) the dark-bordered fibre is represented in continuity with it. The outlines of this band are irregular; and in some places it is much wider than in others. This band is five or six times as wide as many fine nerve-fibres which I have seen; and it will be shown that a fibre of the width of these pale fibres in the tissues of the frog generally, is a long distance from its finest divisions. The same observer makes the nerves of insects terminate in a collection of granular matter within the sarcolemma.

1. *The Distribution of Dark-bordered Fibres not so limited as generally supposed.*

With regard to the distribution of the dark-bordered fibres to voluntary muscle, I would remark

That, although some muscles appear to be very sparingly supplied with dark-bordered nerves, the fibres of certain muscles (for example, the inferior muscle of the eye of the frog) are crossed by bundles composed of two or more fibres at intervals of about the fiftieth of an inch *. The distribution of nerve-fibres to the pectoral muscle is by no means so limited as would appear from cursory examination. It is clear that many branches, resulting from the division and subdivision of some of the large dark-bordered fibres, supply the elementary fibres near the centre of the muscle; and to some muscular fibres four or five of the branches resulting from the subdivision appear to be distributed. These branches divide on the surface of the elementary muscular fibres, but their subdivisions gradually become too fine to be followed. Some branches divide and subdivide into very fine fibres, which are lost amongst the connective tissue upon and between the muscular fibres. But it must not be supposed that all the nerve-fibres of the bundle are arranged thus; for many pursue a much longer course. Bundles composed of two or three dark-bordered fibres leave the large trunk and pursue a long course obliquely across the surface of the muscle. The fibres of each trunk divide and subdivide; and many of the branches which result reach almost to the extremities of some of the elementary muscular fibres. Many pass between the muscular fibres, and, after pursuing a

* The muscular fibres of the diaphragm of the mouse are crossed by bundles of dark-bordered fibres at short intervals along their whole length, and nerve-fibres may be seen at the points where they are inserted into the central tendon.

very long course, gradually become finer by division, and at last terminate in a lax network of fine fibres which pass in and out between the muscular fibres; while some of the subdivisions are distributed to the elementary muscular fibres, like the set of fibres first alluded to. It appears, therefore, that in various parts of the muscle, not merely near its centre, but also on some of the fibres near their insertions, branches of dark-bordered fibres can be seen to become suddenly attenuated and give off very fine fibres which divide and subdivide on the surface of the sarcolemma, becoming gradually finer until lost, or they leave the surface of the elementary fibre and are lost in the intermuscular connective tissue—and other fibres, which gradually become attenuated and, after very numerous divisions, terminate in a network of fine fibres which may be traced for a long distance amongst the fibres of connective tissue, between or upon the elementary fibres. Many of the bundles of dark-bordered fibres above alluded to can only be detected in well-prepared specimens which have been soaked for some time in glycerine, so that the muscular fibres may be separated from each other without rupture of the nerve-fibres or capillaries.

Again, numerous branches of nerve-fibres, composed of two, three, or four dark-bordered fibres, may be seen ramifying and dividing near the tendinous extremities of the muscular fibres of the mylo-hyoid muscle of the frog. Several branches can be followed from the central tendon as far as the central part of the fibres; and often very fine fibres can be seen passing amongst the fibres for some distance and forming networks or plexuses.

But there is another fact against the view that the nerves are distributed to only a very small portion of the elementary muscular fibres of the frog. In certain parts of the pectoral muscle new muscular fibres are being developed, as KÖLLIKER has mentioned, and here in a comparatively small space may be seen elementary fibres varying very much in length and diameter. The thickest of these narrow fibres, according to my measurements, are often not more than the $\frac{1}{1000}$th of an inch in width, and the thinnest not more than the $\frac{1}{10,000}$th of an inch in diameter: some are as long as the other muscular fibres; but often single spindle-shaped fibres with two or three nuclei, or more elongated fibres the nuclei of which have divided so as to form a row of perhaps ten or more, may be found. A large nerve-fibre, generally composed of two large dark-bordered nerve-fibres in the same sheath, with finer fibres, can be followed to the oval swelling situated amongst the ordinary muscular fibres; and one or two dark-bordered fibres *leave* the swelling to be distributed on more distant muscular fibres. The dark-bordered fibres divide, and their branches pursue a very tortuous course in the oval swelling, so that one cannot be followed for any great distance; but fine fibres may be seen passing in either direction, and running parallel with the thin growing muscular fibres. Not unfrequently I have seen these nerve-fibres become so fine that they cannot be followed far; but their course can be traced by their nuclei for a considerable distance. In many instances branches of other nerve-fibres pass to these narrow muscular fibres at a point between the oval swelling and the points of insertion of the fibres. The oval swelling itself consists of very young muscular fibres in various stages of development,

and nerve-fibres. My observations therefore agree in the main with those of Kölliker, who has stated that at these oval swellings the development of new muscular fibres takes place in the fully formed muscle. Upon comparing the above description of these very interesting bodies ('nerve-tufts') with that of Prof. Kölliker, some most important differences will be noticed. After describing the very fine transversely striated muscular fibres which exhibit the 'peculiar swellings with the coiled nerve,' he says, "in the situation of the swelling the finer component fibres of the bundle cling fast together, even after the operation of the alkali (strong solution of potash); and a certain amount of striated granular uniting matter is found between them, which may be partly the remains of fine nerve-fibres and capillaries, and some accompanying connective tissue." Prof. Kölliker next states it as his opinion that the fine muscular fibres are generated by the division of thicker muscular fibres, and suggests that "the nerve-tufts arise from a simultaneous growth and division of the nerve-fibre belonging to the parent muscular fibre, in order that each of the young muscular fibres may obtain its branch of nerve." In my specimens there is no evidence of the very fine muscular fibres being formed by the splitting of a coarser fibre. On the contrary, every fine fibre seems to be developed from nuclei, and to grow in two directions from the oval swellings. With these developing muscular fibres are young nerve-fibres; and the latter seem to be carried, as it were, upon the muscular fibres as their length increases. The oval swelling exhibits a most beautiful and elaborate structure, which is not shown in Prof. Kölliker's drawings*. The minute anatomy of these 'nerve-tufts' will form the subject of further investigation. Not only do dark-bordered nerve-fibres proceed from the oval swelling and pass to their distribution to fibres at a distant part of the muscle, but fine fibres may be followed in some cases almost throughout the entire length of those very fine muscular fibres, many of which are often equal to the ordinary fibres in length. These very fine nerve-fibres divide into branches as they pass parallel to the muscular fibre; and transverse branches can be seen crossing the fibre at short intervals (Plate XLIV. fig. 30).

From these observations I think it probable that the muscular fibre is supplied with nerves in its entire length, and that the branches form a lax network of very fine fibres on the surface outside the sarcolemma. As the muscular fibre increases in size, the finest branches of the nerve are more difficult to demonstrate; and the accumulation of connective tissue external to them increases the difficulty of our seeing these very fine delicate fibres; for it is certain that many active nerve-fibres are much finer than is generally supposed, certainly less than $\frac{1}{100.000}$th of an inch in diameter.

2. *The fine Fibres extend further than* Kühne *and* Kölliker *have traced them.*

With reference to the free terminations of Kühne, Kölliker and others, it may be remarked,—

1. That as it is admitted that the nerve-fibre undoubtedly extends beyond the last

* Proceedings, No. 50, fig. 4, p. 78.

nucleus (Plate XLI. fig. 1, after KÜHNE, figs. 2, 3 *a*, *b*), it is possible, and indeed probable, that it is continued onwards for a greater distance than it has been followed in KÜHNE's specimens. As a rule, it becomes too delicate and transparent to be traced further than has been represented in my drawings (figs. 14, 16, 18, 19); but I submit that the evidence adduced in favour of these ends being *actual terminations* of the nerve-fibres is very far from conclusive. Capillaries, when stretched and torn, give rise to a very similar appearance; and it is not uncommon to find an undoubted capillary vessel which gradually becomes fainter and fainter *until every appearance of it is all but lost*, and this even when the tube remains quite perfect. I have proved this in the case of capillaries, distributed to muscle, which had been injected with prussian blue injection, and so stretched that the injection was removed from the tube for a certain distance. In this space the vessel could not be recognized, and all that could be seen was a faint granular appearance. We therefore cannot conclude that nerve-fibre or capillary ceases, merely because we cannot follow it in certain specimens beyond a certain point. It may exist but be quite invisible.

2. In various tissues to which nerves are abundantly distributed, the appearance represented in fig. 3 *a* is common. This looks as if the fibre extended from the nucleus in opposite directions; while the common appearance, represented in fig. 3 *c*, in which two fine fibres are seen running together, is strongly in favour of the view that very fine nerve-fibres run for a considerable distance beyond the point at which the dark-bordered fibre can be demonstrated, without terminating in ends. It will be observed that the fine fibres represented in my figures are not one-sixth of the diameter of KÜHNE's terminal fibres; and I have seen many fibres much finer than those represented in fig. 3.

3. The finest nerve-fibres visible by the highest powers can often be proved to divide into two fibres, by tracing them to the point where they pass into a fibre running at right angles (fig. 4 *a a*).

4. I have some preparations of the bladder of the frog, in which very distinct networks composed of very fine nerve-fibres are readily seen. One of these, magnified by a power of 1700 diameters, is shown in fig. 6. This, it might be remarked, is not completely conclusive in favour of nerves forming circuits; for it is possible that fibres may diverge from the bundle with which they run and end in free extremities or in small cells, as represented in fig. 5. Numerous observations are against this view; and I regard certain nuclei from which two or three fibres pass in different directions (figs. 2, 3, *a*, *b*) as the peripheral and active portion of the nerve-fibre in all cases. Even in the case of the finest fibres, when a nerve joins another branch running at right angles to it, fibres are given off which pursue opposite directions (apparently pursuing opposite courses), towards the centre, and towards the periphery.

5. With regard to the size of the finest nerve-fibres, I have traced fibres from true dark-bordered nerves which are certainly less than the $\frac{1}{10,000}$th of an inch in diameter, and these are probably composed of more than two fibres. Still finer fibres of this description have been traced to and from ganglion-cells. The connexion between such very fine

fibres and definite dark-bordered fibres has been demonstrated in many situations (tongue, heart, peritoneum, muscular fibre, and very clearly indeed in the bladder of the frog). I have convinced myself that in many of the ganglion-cells of the frog (abdominal cavity, ganglion on posterior roots of the nerves, heart, bladder) one fibre springs from the central part of the cell, while other fibres are in connexion with its circumference. The latter fibres very frequently are arranged spirally around the central fibre. As already stated, many of the finest fibres are less than the $\frac{1}{100.000}$th of an inch in diameter.

It will be said that these fine fibres are composed of connective tissue; but I shall show that the fibres resulting from the subdivision of those which are the direct continuations of the dark-bordered nerve-fibres exhibit the same characters, and can be distinguished from the fine fibres of yellow elastic tissue. Very many fine fibres which are undoubted nerve-fibres, and which form plexuses and networks, have altogether escaped observation, and their nuclei have hitherto been considered as belonging to the connective tissue. The fine nerve-fibres I have described cannot be seen in specimens immersed in water, or in solutions which refract like water.

The Division and Subdivision of the Dark-bordered Fibres.

The numerous divisions and subdivisions of the dark-bordered nerve-fibres have been described and figured by various observers; but it is necessary to give new drawings of some of these fibres, as their arrangement has not been accurately delineated, and the presence of *very fine nerve-fibres in the sheath* external to the white substance has not been admitted. Fig. 11, Plate XLII. shows that the dark-bordered fibres, even in the trunks, may become so thin as scarcely to be visible as distinct fibres by the $\frac{1}{75}$th of an inch object-glass. One of the fibres resulting from the division of *a* may be traced towards the right, and at *d* becomes so thin that it might be easily overlooked, and if recognized would be regarded by most authorities as a fibre of connective tissue in the sheath of the nerve.

Often a fibre resulting from the subdivision of a dark-bordered fibre is seen to pass towards another dark-bordered fibre, and run parallel with it for some distance. This arrangement, which exists in the larger fibres, and which is figured in my last paper, is also observed in the finer ramifications. The terminal dark-bordered fibre very gradually, or more or less abruptly, becomes finer, and divides into two fine fibres; but there is no *termination* or *cessation* of the white substance, as described by KÜHNE, who states that the *white substance* ceases at the sarcolemma, while the *axis cylinder* only is continued onwards as a pale fibre beneath the sarcolemma. KÖLLIKER states that, "besides the axis cylinder, they are furnished with a prolongation of the membranous sheath; indeed I have seen this so clearly in a great many favourable instances, that I can have no doubt on the point. . . . . But whilst it is easy in most cases to perceive the membranous sheath and its enclosed matter distinct from each other at the commencement of the pale fibres, yet in their further progress these structures coalesce together, and the terminal fibres then appear as uniform pale filaments."

My specimens lead me to the conclusion that near the periphery the axis cylinder of a nerve-fibre cannot be distinguished as a separate structure from the white substance. The axis cylinder and the white substance seem to be, so to say, incorporated together to form the terminal part of the dark-bordered fibre. The dark-bordered nerve-fibre gradually becomes narrower as we approach its ultimate distribution, and it is resolved into several fine fibres; but even in threads which are so fine as only to be scarcely visible the material appears to be of the same composition as the thicker parts of the fibre, and by the slow action of acetic acid globules of fatty matter are set free (Plate XLI. figs. 7, 8, & 9). I cannot but think that the very abrupt cessation, or sudden breaking off, of the white substance indicated in some of KÜHNE's drawings is due to the pressure of the thin glass upon the surface of the specimen, which renders comparatively large dark-bordered fibres quite invisible at the point where they cross the convexity of the muscular fibre.

The white substance often diminishes in diameter rather abruptly, but it never ceases in the manner KÜHNE has represented*; and I have never seen any appearances which lead me to conclude that the axis cylinder is prolonged independently of the white substance; nor do I think that "here and there at least a thin *layer* of the white substance extends along the pale fibre," as KÖLLIKER remarks.

The ultimate Distribution of the Nerves in the Cutaneous Muscle from the Breast of the Frog.

Let me now describe more particularly the results of my own observations on the ultimate distribution of the nerves to the muscular fibres of the frog. The fibres resulting from the division of the dark-bordered fibres, which to low powers appear terminal, are often seen to pass over the surface of a muscular fibre, and then become either suddenly attenuated, or gradually thinner as they cross in succession several elementary fibres of the muscle, or pursue a longitudinal course in the intervals between two fibres. In both cases they often give off several branches. In the drawings of KÜHNE the outline of the pale fibres is irregular, and their precise connexion with the dark-bordered fibre is not clearly indicated. In Plates XLII. & XLIII. figs. 11, 12, 13, 14, 15, & 17, it is seen that the dark-bordered fibre divides into two branches, and each branch may be followed for some distance as a definite but very narrow line (less than $\frac{1}{80.000}$th of an inch in diameter). This appearance is constant, and exists in every 'terminal' fibre. Nuclei are connected with these fine 'terminal' fibres, which are but the extension of the dark-bordered fibres; and nuclei are also seen at intervals imbedded in the substance of the highly refracting matter of which the dark-bordered fibres are themselves composed. These nuclei are always to be found imbedded in the white substance near the finer divisions of the dark-bordered fibres (Plates XLI.–XLIV. figs. 8, 9, 11, 12, 14, 18, & 31). Around the fine fibres prolonged from the dark-bordered fibre, may be traced for some distance what appears to be the *outline of the sheath* (Plates XLII. & XLIII. figs. 13 & 16);

* The thickness of the dark-bordered fibre just before it divides, as for example in the case of a fibre in fig. 13, Plate XLII., is often increased by the shortening caused by the *contracted* state of the muscular fibre at the time of preparation.

but these lines may often be seen to divide and subdivide into several very fine fibres, which may run with the prolongation of the dark-bordered fibre, or at once diverge from it (Plate XLIII. figs. 17, 18, & 19; Plate XLIV. fig. 31).

Not unfrequently very fine fibres can be traced *external* to what appears to be the outline of the sheath of the nerve, and these form, with the fine fibres already described, a 'pale fibre.' The band or pale fibre divides into smaller bundles, and the fibres composing them gradually become so fine as to be invisible. Nuclei exist in connexion with the finer fibres which I have described, as well as in connexion with the prolongations of the dark-bordered fibres (Plate XLII. figs. 13, 14, & 15). Here, as elsewhere, some fibres appear to be connected with the nucleus, while others pass round it on one side (Plate XLI. figs. 2, 3 *c*). Sometimes fibres pass on both sides of the nucleus. The pale bundles of very fine fibres often give off branches, and these again divide into finer bundles, producing the appearance of a network (Plates XLII. & XLIII. figs. 13, 14, 15, 16, & 17), the meshes of which vary much in diameter. Very often several nuclei are seen at the point where the dark-bordered fibre divides. A very confused appearance often results from the number of nuclei and fibres. As already stated, in specimens examined in aqueous fluids which do not refract highly, it is not possible to trace the course of the separate bundles of fibres and their connexion with the nuclei; but in specimens mounted in glycerine, examined with high powers, the bundles of fine fibres can be separated from each other and followed (Plate XLIII. fig. 21). Some appear to come from the sheath, or are external to it; and others result from the division of the dark-bordered fibre (Plates XLII. & XLIII. figs. 15 & 17). The nuclei and fibres can be very readily demonstrated near the trunks of the dark-bordered fibres, and the network can often be seen in the same situation, but it is not easy to trace the course of the delicate fibres over the muscular fibres for any great distance. The large nerve-fibres prevent the finer ones from being ruptured; but at a distance from the coarse fibres, there being nothing to protect them, the very delicate fibres are generally destroyed by the necessary manipulation, or rendered invisible by the pressure of the thin glass. I have, however, seen such a network very distinctly on the side of some muscular fibres, upon which numerous branches from an adjacent nerve could be traced at intervals for the distance of about one-hundredth of an inch. Indications of the existence of such a network (the nuclei being perfectly distinct) are not unfrequently seen in many parts of the same elementary fibre. Nuclei and fine fibres, resembling those which have been shown to be in connexion with nerve-fibres, can often be seen just at the edge of a muscular fibre, and very frequently a true nerve can be traced, running for some distance near a capillary, and giving off branches with nuclei which are gradually lost on the surface of the muscle or amongst the connective tissue. As these branches pursue the course described, they can hardly be vascular nerves; and there are besides them other branches which lie closer to the vessel, which are probably of this nature. The distribution of very fine fibres can sometimes be traced by the course of the nuclei. In certain cases, in which no fibre connecting nuclei can be detected when the specimen is first prepared, a fibre afterwards

becomes quite distinct. As I have succeeded in following very fine compound fibres for a considerable distance as they passed amongst several adjacent muscular fibres, I feel satisfied that many apparent ends result from the fibres becoming too delicate to be followed beyond this point. Very slight pressure of the thin glass renders even dark-bordered fibres quite invisible; and very moderate stretching renders undoubted nerve-fibres so very fine that they cannot be seen, or, if they remain visible, all characters which would enable us to identify them as nerve-fibres are completely lost. But even if no such appearances as those I have just referred to existed, it would be more in accordance with what we have learnt from many investigations, to conclude that the fibres really extend further than we are able to follow them, than to assume that they absolutely cease at the point at which, having very gradually become finer and finer, they are no longer visible to us. Moreover, as I have already stated, dark-bordered fibres are to be demonstrated in all parts of the muscular fibre, even upon the tendon near its connexion with the muscular fibres. It is hardly likely that this distribution of coarse fibres over the general surface of the muscles should be associated with a very partial and unequal distribution of the fine fibres which result from their division. As the broad pale fibres described by KÜHNE are really composed of several fine fibres (Plates XLII. & XLIII. figs. 14, 16, 18, & 20), which are often connected by transverse branches so as to form a network, and as the fine compound fibres gradually become finer and finer until they cease to be visible, it is still more improbable that what appeared to him and KÖLLIKER to be ends should be real natural terminations, than if the arrangement had been as KÜHNE has described it. It seems therefore to me that the only inference which can be drawn from the facts demonstrated is, that the nerves terminate in a network: but there are still two modes of arrangement possible with regard to the distribution of this network.

1. It may be confined to one part of the muscular fibre.
2. It may extend down the fibre throughout its entire length.

It is true that the network (Plate XLII. figs. 13, 14) which is so readily demonstrable near the plexus of the dark-bordered fibres very soon becomes so faint as to be lost. The meshes are smaller near the large branches of nerve-fibres than further away, and it is at this point that the rupture of the fibres takes place when the muscle is caused to contract violently soon after death. There is therefore no doubt that the fibres of the pectoral muscle receive a greater supply of nerve-fibres near their central part than nearer their extremities; but it is quite certain that the supply of nerve-fibres is not *limited* to this portion of the muscle.

Although I have never been able to demonstrate uninterruptedly the fibres of such a network over more than the $\frac{1}{100}$th of an inch of a fully-formed fibre of the breast-muscle of the frog, I have succeeded in doing so several times in the case of fibres undergoing development, and about the $\frac{1}{3000}$th of an inch in diameter (Plate XLIV. fig. 30). Upon these I have seen such a network, and I consider that the evidence in favour of the existence of a network extending from one end to the other of the muscular fibre of the voluntary muscle of the frog, though by no means equally distributed over every part

of the fibre, is so strong as to justify me in concluding that such an arrangement is actually present. If the nature of the tissue under examination be considered, and the extreme delicacy of the nerve-structure which has actually been demonstrated be fairly taken into account, no surprise will be felt that the network has not been actually demonstrated throughout the entire length of the large elementary muscular fibres of the frog. The network of fine fibres I have described exactly corresponds in its arrangement with networks which are demonstrated with comparative facility in the palate, bladder (Plate XLI. fig. 6), peritoneum, cornea, skin, and other situations in the frog. In the heart and tongue, networks also exist, but the fibres are very fine, and the meshes are wider. The network, composed of very fine fibres, lies on the same plane as the capillary vessels, and just upon the surface of the sarcolemma. The fine nerve-fibres often lie very near to the capillaries.

The capillaries and the fine nerve-fibres with their nuclei are connected together by a membranous tissue so thin and delicate that its existence can only be proved after it has been coloured, or when some foreign particles have adhered to it. That it is, at least in some places, *distinct from the sarcolemma*, is easily proved in the muscles of the frog, in which animal the sarcolemma is very thick, as it can be stripped off leaving the sarcolemma. I have some specimens in which the muscular tissue has been withdrawn from the tubes of the sarcolemma, so that the nerves can be seen very distinctly. From a part of the surface the thin membrane with nerves and capillaries has been withdrawn, leaving the sarcolemma uncovered. In some specimens, on the other hand, the finest nerve-fibres and their nuclei seem in absolute contact with the sarcolemma, and appear to be adherent to or connected with it; and I incline to the opinion that some of the nuclei which appear imbedded in the sarcolemma are connected with the nerve-fibres.

The pale fibres described by Kühne and Kölliker are compound, and are composed of many very fine fibres, and they divide into bundles of fine fibres which form a network. Each 'pale fibre' consists (1) of a very fine fibre prolonged from the dark-bordered fibre, and (2) of very fine fibres continuous with those in the sheath of the nerve. The fibre which is the immediate prolongation of the dark-bordered fibre, as well as the fine fibres amongst which it runs, can be followed to nuclei, and often a lax network can be traced. The dark-bordered fibres are all continued as very fine fibres; and the subdivisions of these, a short distance from the dark-bordered fibre, are too thin to be measured, even when examined by the highest powers made. The subdivisions of all nerve-fibres pass into fibres which have hitherto been included with the fibres of connective tissue.

The same arrangement with regard to the distribution of the nerve-fibres is observed here as elsewhere. The fibres of the network are composed of numerous very fine fibres. Not one individual fibre can be followed for any distance; but certain delicate fibres can be traced from one compound fibre to another, in precisely the same manner as the coarser fibres can be followed in a plexus. In fact, from all that I have observed in examining the finest branches of the nerve-fibres in various tissues, I cannot but conclude that the general disposition of these finest fibres is the same as that of the coarser trunks and fibres. In passing from the trunks towards the ultimate distribution, it might be said that we

meet with finer and still finer plexuses—the finest visible fibres being probably composed of more than a single fibre.

The chief differences observed between the arrangement of the nerves in the muscular fibres of the mouse, described by me in the Philosophical Transactions for 1860, and those of the frog, are, that the fibres are much finer in the latter than in the former, and the fibres themselves, and the nuclei in connexion with them, are much more abundant and closer together in the mouse than in the frog. The position of the fibres with regard to the sarcolemma and the muscular tissue, and their relation to the capillaries, is the same in both.

I now pass on to the consideration of the fine fibres connected with the nerves, and often seen running in the sheath with the dark-bordered fibres, which have already been alluded to in this paper. These fibres have been regarded as fibres of connective tissue, but they have not been carefully studied. The evidence in favour of these being real nerve-fibres is as strong as that upon which the nervous character of the fine fibres, which are the direct prolongations of the dark-bordered fibres, rests.

Fine Nerve-fibres imbedded in the Sheath.

The following observations are of the greatest importance with regard to the general question of the mode of distribution of nerve-fibres.

As a dark-bordered nerve crosses the muscular fibres, it often gives off several very fine branches. In Plate XLIII. fig. 19 a nerve is represented from which two branches are seen to proceed and divide upon the surface of the same muscular fibre, and other branches are given off a short distance from the point at which these branches leave the trunks. These fibres are not connected with *those portions of the dark-bordered fibres seen in the figure*, although their arrangement exactly corresponds with the fine fibres prolonged from the dark-bordered fibres. Compare the fibres marked *b*, *b* in fig. 19 with *b* in figs. 13 & 14. These fine nerve-fibres are very numerous. They often run parallel with the dark-bordered fibres for some distance, perhaps cross them several times, divide and give off fibres which pass off in different directions. The line which appears to be the outline of the tubular membrane of nerve-fibres near their periphery, is frequently found to consist of two or more very fine fibres, which are in many instances connected with nuclei, which, it is generally believed, are the nuclei of the tubular membrane. I have specimens in which five or more very fine fibres can be demonstrated between the dark-bordered fibre and the outline of the tubular membrane (Plate XLI. *et seq.*, figs. 7, 8, 9, *a*, 11, 15, 18, 21, 24, 25, 26, 27, 28, 29, & 31). These branches leave the trunk at intervals and pass to their distribution, or pursue their course with other fibres. Usually two or more pass off at the same point; and in the rare instances in which one fibre passes by itself to its distribution, one can never feel confident that it is really single. In those fortunate specimens in which it can be followed for a short distance, it can be seen to divide into two branches which pursue opposite courses; and very often at the point of division a third fibre can be seen.

The fine fibres I have described are very numerous near the point of distribution of the

nerves (Plate XLIV. figs. 27 & 28), and are to be seen in relation with almost all the dark-bordered fibres, distributed not to muscle only, but to the tissues of the frog generally (palate, peritoneum, intestines, skin, heart, tongue, liver, kidney, &c.). I have also seen fine fibres corresponding to these in the mouse, and believe them to exist in vertebrate animals generally; but being so very delicate, they are more difficult to demonstrate in mammals than in the frog. These fine fibres distributed on the muscles of the frog cannot, by any peculiarity in their appearance, be distinguished from the fine fibres which are in direct continuity with the dark-bordered fibres. It has been shown that in many cases, especially in the muscles of the eye, and in those of young frogs generally, and in the palate of the frog at all ages, dark-bordered fibres can be traced, gradually becoming finer and finer until the fibres are too thin to be followed. *Some* of these fine fibres running in the sheath of the nerve, result from the division of the dark-bordered fibres (Plate XLII. fig. 11 *d*), but it is doubtful if all have this origin. At the same time there are many appearances I have seen in various peripheral nerves which are much in favour of this view. I shall be able to express myself more confidently on this question when the researches upon which I am engaged are completed. A great number of these fine fibres with nuclei, running in the same sheath with dark-bordered fibres, are represented in Plate XLIV. fig. 28, from the bladder of the frog; but they are much more numerous in this organ than in connexion with the dark-bordered fibres distributed to striped muscle. I have seen these fine fibres divide in the same direction, that is *from* centre *towards* periphery, as the coarse fibres; so that in the trunk of the nerve there are dark-bordered fibres which divide as they pass towards the periphery, and finer fibres which divide as they pass in the same direction. In the bladder of the frog there are large bundles of fine fibres passing in the same sheath with the ordinary dark-bordered fibres, as well as numerous trunks composed of fine fibres alone; but in this organ there are many ganglia connected with these fine fibres; so that it is doubtful if the fine fibres I have described in connexion with the muscular nerves are of the same character as the fine fibres in the bladder of the frog. The bundles of fine fibres ramifying in the same sheath with the dark-bordered fibres distributed to the bladder have certainly no connexion with the dark-bordered fibre; but, on the other hand, it is certain that some of the fibres we have been considering are continuous with dark-bordered fibres.

It has been assumed by many observers that a fibre which exhibits the refractive power peculiar to the white substance can alone be regarded as a true nerve; and the point beyond which the white substance cannot be traced has been looked upon as the termination of the nerve. Although pale fibres have been recognized in certain situations, and their continuity with dark-bordered fibres traced, still the general idea seems to be that all true nerves exhibit the dark contours. The pale fibres described by Kühne as lying beneath the sarcolemma, and by Kölliker upon this membrane, are regarded as the terminations of dark-bordered fibres with which they are continuous. These pale fibres, which are composed of many fine fibres and have been traced so short a distance from the dark-bordered fibres in certain instances, are, in my opinion, *only*

the commencement of that portion of the nerve-fibre which influences the muscle and corresponds with the *fine fibres composing the network in the bladder* of the frog (Plate XLI. fig. 6). From what I have seen of the distribution of nerves to tissues generally, I feel convinced that the really important part of the peripheral nerve-fibres, by which the various tissues under the control of the nervous system are influenced, really only commences at the point where the white substance seems to cease. Beyond this point, and continuous with the dark-bordered fibres, there is a most extensive system of fine fibres with which nuclei are connected. The fibres are compound, and the arrangement of the bands is such as to produce the appearance of a network, in the meshes of which the active elements of the tissue are situated.

The relation of Nerve-fibres to the Connective Tissue of Muscle.

I have shown that the network of delicate compound nerve-fibres on the surface of the muscular fibres is continuous with certain fibres and nuclei which *seem* to belong to the connective tissue around the muscular fibres (p. 892). This connective tissue is thicker in old animals than in young ones, and may be regarded as constituted mainly of the remains of a structure which was active at an earlier period of life. These remarks do not in any way apply to the fascia of a muscle, but only to the indefinite connective tissue beneath it, and in close contact with the sarcolemma and between the muscular fibres.

Many of the fibres delineated by KÜHNE in fig. 15, plate 4 of his memoir, and termed by him fibres of connective tissue, are made exactly to resemble the pale nerve-fibres; and their nuclei are of the same size. The fibres of 'connective tissue' (?) which leave the sides of the dark-bordered fibres represented in his drawings do not accord at all with appearances I have seen, which are much more positive. KÜHNE gives a nucleus lying outside the white substance with indefinite fibrous tissue proceeding from it. In my specimens such a nucleus is seen continuous with definite fibres in the 'matrix' external to the white substance (Plates XLIII. & XLIV. figs. 17, 28, & 31). From the nucleus definite fibres can often be traced in opposite directions; and on one side of it three or four fine fibres may often be demonstrated (fig. 31). It is unnecessary here to repeat the various arguments that have been adduced in favour of the view that these fibres are veritable nerve-fibres, and not mere connective tissue. This important question is decided by some preparations I have made showing the distribution of the nerves in the bladder of the frog*; and I am sure it will be admitted, at least by those who have seen

* KÖLLIKER, speaking of the distribution of the nerves, says, "The same mode of termination as in the heart (very fine pointed extremities) prevails in the non-striated muscular tissue of the pharynx and bladder of the frog." I have fully investigated the arrangement of the nerve-fibres in the bladder of the frog, and have given drawings of the appearances I have observed in this paper, and also in No. XII. of the 'Archives of Medicine.' I can follow the finest nucleated fibres for long distances; but they always pass to other fibres, and never terminate in any ends that I can discover. In many situations there is a network with comparatively small meshes, as represented in Plate XLI. fig. 6. Amongst the delicate striped fibres of the auricle of the heart of the frog I have also seen bundles of very fine fibres forming networks with large meshes; but I have never seen ends, and feel sure that free ends do not exist in these tissues.

my specimens, that the appearances represented in the drawings accompanying this paper are incompatible with the conclusion that all the fine fibres I have described are merely fibres of connective tissue.

Since it has been shown that many of the corpuscles in the connective tissue between the muscular fibres, and in other situations which are usually considered to be connective-tissue corpuscles, are really connected with the nerve-fibres, and that the quantity of the connective tissue increases as the muscle advances in age, it remains for those who still maintain that this indefinite connective tissue is a structure developed specially for the support or nutrition of higher tissues, to explain, according to their view, its absence when the tissues are undergoing most active changes, during development, and when they are softest and therefore are in greater need of support, and how and at what period it comes into relation with the nerve-fibres,—why it is more abundant on the muscles of the tongue and diaphragm of the mouse than on the muscles of the limbs,—and many other facts which I have considered elsewhere, and which appear to me to be not only strongly opposed to this view of the origin of this form of connective tissue, but incompatible with it*.

In adult animals the connective tissue is too thick to permit our seeing the arrangement of the very much more delicate nervous structure beneath it; and the difficulty is further increased by the circumstance that the light must first traverse the muscular fibre itself. The relation of the nerves to the sarcolemma remains constant; but the connective tissue exists in greater quantity and is firmer and more fibrous in old than in young muscles, and forms a fibrous stratum external to the nerve-fibres. If we attempt to tear off this connective tissue in order to see the nerve-fibres beneath it more distinctly, we almost invariably tear away the nerves and vessels also; for these structures are undoubtedly connected with the connective tissue.

It seems to me that many of the appearances observed receive at least a partial explanation from the following considerations. The muscle grows, gradually, until it attains perhaps twenty times the size it exhibited in the young frog. That part of the nerve-fibre which in the young animal might be said to be terminal, would in the larger muscle correspond to trunks from which branches were given off in different directions; and fibres and nuclei which were in contact with the muscular fibres would be removed, as the muscle grew, further and further away from the sarcolemma, but they would still be connected with the new fibres and nuclei which are developed just external to this membrane. Thus we should have a quantity of tissue composed of modified nuclei and wasted nerve-fibres which would accumulate as the muscle advanced in growth, and through which many of the nerve-fibres would be seen to pass. Many of these nuclei and fibres having been originally continuous with the nerve-fibres would still retain connexion with them, but this connexion is not necessarily a physiological one.

Other explanations might be offered, but I desire now only to draw attention to the fact that *all* nerve-fibres at their periphery are continuous with exceedingly delicate

* "The Structure of the Simple Tissues," Lectures VI. and VII.

fibres which have hitherto been regarded as belonging to connective tissue, but which differ from very fine yellow elastic fibres in their granular appearance, in their mode of branching and the curves which they form, in refractive power, and in the alteration resulting from the prolonged action of dilute acetic acid*.

It seems quite possible that complete nervous circuits may exist, and the delicate fibres of the plexus may be connected with delicate fibres from the branches of nerve-fibres ramifying in the connective tissue. Although nuclei (connective-tissue corpuscles) appear to be connected with the nerves in great number, it by no means follows that all these are instrumental to the action of the nervous system†. The nerve-currents would of course pursue the shortest route, and as the position of the fibres must become altered in consequence of the development of new ones, some would no longer be traversed by the nerve-current. The nuclei would slowly alter but would still retain a certain anatomical connexion with the fibres, and might still absorb a certain amount of nutrient matter and slowly produce a low form of fibrous tissue.

Many fine bundles of fibres, and fibres which appear to be single, with nuclei connected with them at short intervals, may be seen ramifying in the indefinite connective tissue in all parts of the frog. The fine fibres are generally considered to be fibres of yellow elastic tissue, and the corpuscles are all included under the head of 'connective-tissue corpuscles'. These fibres may be readily followed (especially on the palate, cornea, and bladder) to undoubted nerve-fibres, and it would not be possible to distinguish one of these fibres from the fibre which is the direct continuation of the dark-bordered nerve-fibre in muscle. I am therefore forced to conclude either that nerves terminate in 'connective-tissue fibres,' or that this form of connective tissue itself results from changes occurring in nerve-fibres and the nuclei or cells which take part in their formation. As this form of connective tissue always exists where nerve-fibres are distributed—as it increases in quantity, but at the same time becomes more condensed as the tissue advances in age—as the meshes formed are smaller and less regular as we recede *from* the surface where nerves ramify—as the so-called fibres of yellow elastic tissue in connexion with the nerves become altered like the nerves themselves by the slow action of acetic acid, while other fibres more distant do not undergo this change, and as these facts have been observed, not in one organ or tissue, but in very many (palate, tongue, cornea, mesentery and other parts of the abdominal connective tissue, muscle, skin, pale muscular fibre), as well as in different animals, I venture to conclude that this so-called connective tissue lying immediately beneath sensitive surfaces, and around the elementary fibres of voluntary muscle, and in other situations where nerves are abundantly distributed, is not a tissue specially formed as a medium for con-

* See some observations on the distribution of nerves to the mucous membrane of the epiglottis of man in No. XII. of the 'Archives of Medicine.'

† Kühne has recently stated that the nerve-fibres are connected with the connective-tissue corpuscles of the cornea; but I have some specimens which demonstrate that this view is erroneous. The nerve-tissue is always distinct from other tissues, and possesses its own masses of germinal matter or nuclei of formation.

necting or giving support to higher tissues, but results from changes occurring in the nervous tissue itself, and that the fine fibres of elastic tissue in indefinite connective tissue were actual nerve-fibres at an earlier period of life *. Thus a low form of tissue, which results from the natural changes taking place during the life and continual growth of the highest tissue, may form a basis of support for the latter. It becomes firmer as the organ or tissue advances in growth, but it does not exist at an early period of development, nor is it a special tissue developed in a certain definite manner like tendon, true yellow elastic tissue, cartilage, muscle, &c.

Conclusions.

1. In certain muscles of the frog the distribution of dark-bordered nerve-fibres is pretty uniform in every part. Although in the case of the pectoral a greater number of nerve-fibres is distributed to the central part of the muscle, fibres may be traced from the large bundle almost to the extremities of some of the muscular fibres. Many branches which easily escape observation pass between the muscular fibres and their subdivisions and supply neighbouring fibres, or are gradually lost in the connective tissue.

2. Fine nerve-fibres are most easily demonstrated on the external surface of the sarcolemma near the nerve-trunks; but reasons have been advanced in favour of the conclusion that every elementary muscular fibre is more or less freely supplied with nerve-fibres throughout its entire length. Many of these fine nerve-fibres on the surface of the muscular fibre become gradually very faint, until from their extreme tenuity we are no longer able to follow them.

3. Fine nerve-fibres in direct continuation with the dark-bordered fibres, and less than the $\frac{1}{30,000}$th of an inch in diameter, have been seen to divide into finer branches which have nuclei in connexion with them.

4. The pale fibres delineated by KÜHNE and KÖLLIKER, and by them considered single terminal fibres, consist of—

a. Fibres about the $\frac{1}{30,000}$th of an inch in diameter, or less, resulting from the subdivision of the dark-bordered fibre.

b. Fibres resulting from the subdivision of fine nerve-fibres ramifying in the sheath of the dark-bordered fibre, or situated external to it.

5. Nuclei are found in connexion with—

a. The dark-bordered fibre itself, near its terminal ramifications.

b. The fine fibres which are the direct continuations of the dark-bordered fibres.

c. The fine fibres in the sheath, or external to it.

6. The nuclei and delicate fibres above referred to are arranged so as to form networks, the meshes of which vary much in size, situated with the capillaries on the external surface of the sarcolemna. The fibres of these networks are compound, and consist of finer fibres, which are distinct from, and do not anastomose with, each other. The

* "On the Distribution of Nerve-fibres to the Mucous Membrane of the Human Epiglottis," in my 'Archives,' No. XII. 1862.

fine fibres continued from some of the dark-bordered fibres, as well as those ramifying in the sheath of the nerves, may sometimes be followed over six or more elementary muscular fibres, and form, with other fine branches, networks, many of the meshes being as wide as a muscular fibre.

7. Fine nerve-fibres, with nuclei connected with them, exist (not unfrequently to the number of four or five) in the sheath of dark-bordered nerve-fibres near their distribution; and some are also found external to what appears to be the outline of the sheath. Some of these result from the subdivision of a dark-bordered fibre. These fine fibres and their nuclei have been included hitherto under the head of 'connective tissue.'

8. The connective tissue around the elementary muscular fibres, and in connexion with the nerve-fibres, is composed of—

a. Nuclei which might have taken part in the formation of the nerve-fibres, but which have degenerated, and a low form of fibrous tissue has alone been produced.

b. Fibres and nuclei which were once active and formed an integral part of the nervous system, but which have grown old, and have been replaced by new nuclei and fibres.

c. The remains of altered and wasted vessels and nerve-fibres distributed to them, and perhaps wasted muscular fibres themselves.

9. The nerves distributed to the voluntary muscles of the frog do not terminate in free ends, but there is reason for believing that complete nervous circuits exist.

10. In all cases the fibres resulting from the division of the ordinary nerve-fibres are so fine that many cannot be seen with a power magnifying less than a thousand diameters, and there is evidence of the existence of fibres which could only be positively demonstrated by employing a much higher magnifying power. It is probably by very fine fibres alone and their nuclei, that the tissues are influenced. The ordinary nerve-fibres are only the cords which connect this extensive peripheral system (which has been traced in different tissues far beyond the point to which the dark-bordered nerve-fibres can be followed) with the central organs of the nervous system.

11. The facts and conclusions above stated, with reference to the distribution of nerve-fibres to the voluntary muscles of the frog, are in accordance with the arrangement of the finest nerve-fibres demonstrated in many other tissues of the same animal, and agree with many appearances observed by the author in connexion with the peripheral distribution of the nerves, not only in certain tissues of man and the higher animals, but also in invertebrate animals.

12. The distribution of the finest branches of the nerve-fibres can only be demonstrated in tissues which have been immersed in fluids which refract highly, as syrup or glycerine.

Explanation of the Plates.

The figures represented have been copied from specimens magnified with a twelfth (700 diameters linear) and a twenty-sixth (1700 diameters linear), made by Messrs. Powell and Lealand. All the figures, with the exception of figs. 1, 2, 3, 4, & 5, have been carefully copied from nature. The relative sizes of the objects represented have been accurately retained. The dimensions of every object can be ascertained by measuring it upon one or other of the following scales; so that in the text I have considered it superfluous to insert the measurements.

Many of the specimens will retain their characters for some time (probably two or three years at least), and can be examined by any one desirous of seeing them. Some of the drawings were traced from my drawings, on the wood blocks, under my immediate direction, others by myself. They were engraved by Miss Powell.

1000th ×700

1000th ×1700

PLATE XLI.

Fig. 1. Terminal fibres beneath the sarcolemma, copied from Kühne's paper. The fibre is as broad as the nucleus, appears smooth, and terminates in a pointed extremity.

Fig. 2. Fine fibres with nuclei, as seen in many tissues of the frog, according to the author's observations. The fine fibres delineated are less than the $\frac{1}{50,000}$th of an inch in diameter, and often become so fine that they cannot be followed; but the apparent terminations are not true ends.

Fig. 3 illustrates the manner in which fine nerve-fibres with nuclei ramify at their distribution. *a*. A nucleus with a fibre passing from either extremity; *b*, fine nerve-fibre branching; *c*, two fibres running parallel to each other.

Fig. 4. Fine nerve-fibres dividing at the points *a a*, where they meet another fibre, into two branches, which pursue opposite directions.

Fig. 5. Network of nerve-fibres to show how the finest fibres might possibly terminate in free extremities or in nuclei, consistently with the existence of networks demonstrated by the author.

Fig. 6. Network of nerve-fibres near the inner surface of the bladder of the frog; each fibre is composed of a number of very minute fibres, which do not anastomose with each other. A dark-bordered fibre was continuous with the fibres of which this network is composed, at a point a little below the lowest fibre represented in the drawing. ×1700.

Fig. 7. 'Termination' of a dark-bordered fibre, showing its continuity with fine fibres arranged to form networks as in fig. 6. A fine fibre (*a*) is seen to run parallel with the terminal part of the dark-bordered fibre (*b*). This is also lost among other fibres of the network. The granular appearance of the fibres in this

specimen results from the slow action of acetic acid. This figure, and figures 6, 8, & 9, show the relation of the fine fibres to the nuclei. ×1700.

Fig. 8. Another terminal 'extremity' of a dark-bordered fibre. A similar fibre (*a*) is seen external to the dark-bordered fibre, as in the last and also in the next specimen. Four nuclei are seen, which exhibit their relation to the bundles of fine fibres.

Fig. 9. Another terminal portion of a dark-bordered fibre. In figs. 7, 8, & 9 a nucleus is seen in the dark-bordered fibre as well as in connexion with the pale fibres. Figures 6, 7, 8, & 9 are from the bladder of the frog.

Fig. 10. Portion of muscular fibre from the leg. Several dark-bordered fibres are seen enclosed in the same sheath; and many of these are exceedingly thin, but evidently possess the same structure as the ordinary dark-bordered fibres. ×700.

PLATE XLII.

Fig. 11. Dark-bordered fibres. The nucleated dark-bordered fibre *a* is seen to divide into two branches. The one passing in the division which diverges to the right, rapidly becomes so very fine that it can hardly be followed as it runs parallel with another dark-bordered fibre and in the same sheath with it (under *d*). This very fine fibre, in direct continuity with the dark-bordered fibre, cannot be distinguished from the fine fibres seen in the sheath of the nerve on the left side of the specimen (at *b*), which leave the trunk and assist in forming a separate branch at *c*. From the pectoral. ×700.

Fig. 12. Division of dark-bordered fibre in the central part of the pectoral muscle of the frog. The fine fibres resulting from its subdivision may be followed for a considerable distance. Nuclei are connected with them at intervals, and the fibres are arranged to form a network. A more perfect example of this arrangement is represented in figure 43 (not published). This figure shows the course of the very fine fibre which is directly continuous with the dark-bordered fibre in certain cases. ×700.

Fig. 13. Division of dark-bordered fibres on the surface of a muscular fibre, from the central part of the pectoral muscle. The muscular tissue having been removed from the tube of the sarcolemma, the delicate nerve-fibres can be distinctly seen on the *external surface* of this transparent membrane. The pale granular fibres, which are here and there connected by branches so as to form networks, are composed of the delicate fibres which are the immediate continuations of dark-bordered fibres (*a* and *b*), and of finer fibres which are derived from those ramifying in the sheath or external to it. Nuclei are connected with these fibres. ×700.

Fig. 14. Division and subdivision of fine dark-bordered fibres on the surface of muscular fibre, showing numerous fine fibres arranged in the form of a network, and nuclei. Two or three of the delicate compound nerve-fibres may be traced quite to the edge of the muscle. Pectoral muscle. ×700.

Fig. 15. Division of dark-bordered fibre with fine fibres ramifying in the sheath of the nerve. From the pectoral muscle. ×700.

PLATE XLIII.

Fig. 16. Distribution of finest dark-bordered fibres on the surface of a muscular fibre from the pectoral muscle. At the edge of the specimen on the left, the delicate nerve-fibres are seen lying, not only upon the external surface of the sarcolemma, but at an appreciable distance from the outer surface. ×700.

Fig. 17. Division of dark-bordered fibre and formation of fine networks. Pectoral muscle of the frog. ×700.

Fig. 18. Very fine nerve-fibres on the surface of the muscular fibre. From the pectoral of a young frog. Several of these fibres can be followed to the edge of the muscular fibre, where they are lost. ×1700.

Fig. 19. Fine fibres from the sheath of the nerve, dividing and subdividing on the surface of two elementary muscular fibres. From muscle of the neck of the frog. ×700 diameters. Compare the appearance of the fibres represented at *b*, *b* in the drawing, with fibres *b* in figs. 16, 15, 14, & 20, which undoubtedly come from true dark-bordered nerve-fibres.

Fig. 20. Division of dark-bordered fibre on surface of muscular fibre.

Fig. 21. Fine dark-bordered fibre, and fibres in sheath of the nerve, with nuclei. From muscle of the neck of the frog. ×700.

Fig. 22. Fine fibres resulting from the subdivision of a dark-bordered fibre ramifying on a muscular fibre. Pectoral muscle. ×700.

Fig. 23. Division of dark-bordered fibres crossing a muscular fibre.

PLATE XLIV.

Fig. 24. Dark-bordered fibre and fine fibre in the sheath ruptured. From muscle of under jaw of frog. ×700.

Fig. 25. Dark-bordered fibre and fine fibres, showing fibres crossing each other and forming very fine branches composed of several finer fibres. ×700.

Fig. 26. Dark-bordered fibres and fine fibres in sheath between muscular fibres of the pectoral muscle of the frog. ×700.

Fig. 27. Dark-bordered fibre, with fine fibres external to it, ramifying between the elementary muscular fibres of the pectoral muscle of the frog. ×700.

Fig. 28. Branching and division of dark-bordered nerve-fibre near terminal branches, and bundles of fine fibres. Several nuclei are seen in connexion with both sets of fibres. From the bladder of the frog. At *a* the dark-bordered fibre becomes resolved into several fine fibres. ×700.

Fig. 29. Fine fibres continued from a dark-bordered fibre, and the fibres in its sheath crossing a young muscular fibre. ×700.

Fig. 30. Young muscular fibre from the pectoral muscle of the frog, near one of the

oval swellings. At *a* and *b* are seen the fine fibres which are continuous with the dark-bordered fibres. These are gradually lost amongst very fine fibres. The compound branches divide and subdivide on the surface of the muscular fibre. ×700.

c. Another fibre at a distance from the oval swelling, showing nuclei with very fine fibres ramifying upon the muscular fibres. ×700.

Fig. 31. Dark-bordered nerve-fibre with fine fibres at the side of it. These fine fibres appear in one part like the outline of the tubular membrane, but at a short distance they are seen to give off branches which pass with other fine fibres. It will also be observed that there is no corresponding line on the other side of the dark-bordered nerve-fibre in this case. From bladder of frog. ×700.

It will be doubted by some if the fine fibres I have figured are true nerve-fibres; but it must be borne in mind, (1) that dark-bordered nerve-fibres divide into fibres as fine as these in the trunks of the nerves near their distribution; (2) that fibres as fine as these form the direct continuation of dark-bordered nerve-fibres themselves; (3) that all dark-bordered nerve-fibres terminate in fine fibres which divide and subdivide into finer branches which run in company with fine fibres apparently derived from the sheath of the nerve or from fibres external to the sheath, but which are probably true nerve-fibres and, at least in some cases, are themselves but the continuation of dark-bordered fibres which run for some distance in the sheath and then diverge.

XXXVI. *Researches on the Development of the Spinal Cord in Man, Mammalia, and Birds.* By J. Lockhart Clarke, *F.R.S.*

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In the Philosophical Transactions for 1859, I showed that, in the adult spinal cord of Man and all vertebrate animals, the white columns as well as the grey substance are everywhere interspersed with granular nuclei, of which some are attached to the sheaths of the primitive nerve-fibres, while others are imbedded in the intervening connective tissue. In the grey substance these nuclei are more abundant than in the white, and have much resemblance to many of the free nuclei or cells, which are certainly in connexion with nerve-fibres, and with which they are freely intermixed. With the hope of throwing some light on the histological relation between these and the other elementary tissues of the cord, the following inquiries into their development were undertaken.

The histology of the development of the spinal cord in Birds and the higher animals had already been begun by Bidder and Kupffer*, and pursued a little further by Kölliker. The results of their investigations are comprised in the following statements:

1. After the closing of the laminæ dorsales, the cord at first consists of a canal, the walls of which are composed of cells of one uniform kind, and disposed in a radiating form.

2. In the next place, this wall of cells divides into two layers, of which the outer forms the grey substance, while the inner one appears as the lining of the central canal.

3. The white substance makes its appearance later than the grey, by the cells of which it is without doubt furnished as an outer layer or covering. The white columns are four in number, two on each side; and to these a white commissure is added. There are no lateral columns; those which are so called are subsequently formed as an extension of the anterior columns†.

The investigations of which I now communicate the results were made on embryos of the domestic fowl, of the Sheep, Pig, Ox, and Man. The fluid employed in the process of hardening was at first a weak solution of bichromate of potash, and then a similar solution of chromic acid. When sufficiently young, the embryos were immersed in the solution without mutilation; but in the more advanced states of development the spinal cord was previously uncovered.

* Untersuchungen über die Textur des Rückenmarks, und die Entwickelung seiner Formelemente. Leipzig, 1857.

† Kölliker, Entwickelungsgeschichte des Menschen und der höheren Thiere. Leipzig, 1861, pp. 259, 260.

In a fœtal sheep nine lines in length, a transverse section was made through the spinal column and cord, at the upper part of the lumbar enlargement. The section of the cord was of an ovoid form, with its longer axis before-backward, but was somewhat broader at its anterior than its posterior half (see Plate XLV. fig. 1). The grey substance occupied nearly the whole of its area, but formed an irregular outline which was not concentric with the surface of the section. The central canal was a mere slit or fissure extending backward and forward to near the surface of the grey substance, particularly at its posterior end. Around this fissure was a somewhat dark layer, which was broad along the sides, as well as in front, where it formed a nearly semicircular projection beyond the rest of the grey substance, and was covered externally by the rudiment of the anterior commissure (fig. 1, *a*). Posteriorly it reached quite to the surface of the cord, being hitherto uncovered by the white columns, and was joined to its fellow of the opposite side by a shallow bridge of the same kind of substance. When examined by means of high magnifying-powers, this layer was seen to consist of closely aggregated nuclei connected together by a continuous network of short fibres. The nuclei in size were a little unequal, but their average diameter was about equal to that of the blood-globules. In shape, also, they were somewhat diversified from the round to the oval, the pyriform or the variously angular; but were all intermingled without regularity or order. From the inner border of the layer, that is, from the verge of the canal, the fibres, although they formed an irregular network with the densely aggregated nuclei, had nevertheless a tendency to radiate outward to the rest of the grey substance. From the outer side of the layer, at its posterior extremity, a somewhat dark and curved process (*b*), forming the lateral boundary of the posterior grey substance, extended outward and terminated in a roundish but imperfectly defined mass (*b'*), midway between the anterior and posterior extremity of the section. This mass, however, was uninterruptedly continuous with the outer border of the layer surrounding the canal, as well as with the anterior grey substance, by means of a paler portion composed of similar material. The surface of the mass and concave surface of the process which joined it to the posterior extremity of the section were overlaid with the rudiments of the posterior white column (*c*, fig. 1). In section this column had an oval figure, and covered only about the two anterior thirds of the posterior grey substance, leaving the other convex third entirely uncovered, except by the rudimentary integuments. By means of a sufficient magnifying-power, it was clearly seen that at the surface of the grey substance the fine network of fibres between the closely aggregated nuclei was directly continuous with the fibres of the white column with which it was overlaid. Fig. 2 represents a portion of a transverse section of the posterior grey and white substances at their points of junction, magnified 420 diameters: *a* is an inner part of the white column, and *b* is an outer part of the grey substance, consisting of nuclei and a close network of fibres continuous with *a*. Through the same network nuclei were connected with some of the fibres of the posterior nerve-roots (*d*), which ran obliquely outward and forward, and made their exit at the anterior border of the posterior column, to enter the intervertebral ganglion (*e*).

The anterior grey substance (*f*, fig. 1) was of a somewhat triangular form, with one of its angles behind and the other two in front. The posterior angle, which projected a little into the lateral part of the antero-lateral column, consisted of a very distinct and dark group of nuclei, and was separated from the posterior grey substance (*b'*) by a much paler structure, composed chiefly of longitudinal and radiating fibres, which formed the rudiments of the lateral column. The anterior and outer angle was more obtuse (like a right angle rounded off), and consisted also of a distinct and dark, but larger group of nuclei, from which the majority of the anterior nerve-roots (*g*) originated, and then proceeded outward and forward, to join the posterior roots which escaped in the same direction from the intervertebral ganglion. At its inner side, the triangular mass, like the posterior grey substance, was continuous with the layer surrounding the central canal by a nucleated network of the same kind.

Throughout the whole of the *posterior* grey substance there was no diversity in the appearance either of the nuclei or of the close network of fibres by which they were connected. In the *anterior* grey substance, however, there was a slight diversity in the appearance of both. The nuclei contained in the separate groups already described were not *larger*, but they were less round or oval, or more irregular in shape, than those of any other part of the section, either anterior or posterior. They had also some tendency to aggregate into small, irregular and imperfectly isolated clusters, which were interspersed with granules and united by a looser and also irregular network, so that the entire structure had more or less the appearance of a sponge-like arrangement. In the central layer surrounding the canal, and of which the inner portion constitutes the epithelium, the nucleated network had a radiating tendency, which decreased on extending outward. In the parts between the separate groups or masses of grey substance, the nuclei were densely but uniformly aggregated, and the network of fibres was less distinct.

The antero-lateral white columns (*h*) were very small in proportion to the quantity of grey substance. Behind, where they joined the posterior columns, they were much shallower, and reduced, indeed, to a mere fringe on each side, sunk in the depression between the anterior and posterior grey substance, from which they were developed as the rudiments of the so-called lateral column. Hitherto the anterior median fissure had no existence, but fibres proceeding from the anterior nerve-roots on each side could be seen to cross each other transversely in front of the epithelial layer which surrounded the canal. These transverse fibres were the rudiments of the anterior commissure.

Surrounding the white columns and enclosing the intervertebral ganglia, there was a quantity of loose tissue, which in front formed a deep layer (*i*), connecting the cord with the body of the vertebra (*jj*), and consisting of a nucleated network, the meshes of which were transversely extended. The nuclei of this network, although much less numerous than those of the grey substance of the cord, differed from them but little in general appearance. Their connecting fibres, however, were thicker, coarser, less granular, and directly continuous, at the surface of the anterior commissure, with

similar fibres which radiated forward from the epithelium (*a*) surrounding the front of the canal. At its opposite or anterior border—or rather anterior part, for it had no distinct border—this nucleated tissue became directly continuous with that which formed the body of the vertebra (*j j*). This body consisted of a dense mass of closely aggregated nuclei, similar at its circumference to those of the connective tissue, but somewhat different in shape toward the centre, where they were round, oval, elongated, angular, and often curiously crescentic. They were all connected by fibres which, nearer the circumference, where the structure was looser, could be very easily distinguished; but in the centre they were less distinctly seen between the densely-crowded nuclei. Near this centre was a circular spot (*k*), the section of a longitudinal cylinder, surrounded by a thick wall resembling the wall of a cartilage-cell and enclosing several closely aggregated nuclei, connected by short fibres. These nuclei were round, oval, pyriform, or otherwise irregular in shape, and rather larger and more granular than those by which they were surrounded.

The spinal cord and vertebral column of the Sheep at this period of development have a considerable resemblance to those of the chick on the fifth day of incubation. In the latter, however, the different parts of the grey substance are more distinctly marked. Fig. 19, Plate XLVII. represents a transverse section of the vertebral column and spinal cord, in the sacral enlargement of the chick, on the fifth day, and magnified 60 diameters. The section of the *cord* was nearly a perfect oval. There was no trace of the rhomboidal sinus or ventricle which in the adult bird separates its posterior lateral halves*. The epithelial layer (*a*) immediately surrounding the canal was clearly defined and easily distinguishable from the rest of the grey substance. It was somewhat broader behind, where it reached the surface in the form of an arch. On each side of it the posterior grey substance (*b*) consisted of a pyriform mass, nearly covered by the rudiments of the posterior white column (*c*), and separated by a triangular and much lighter space from the anterior grey substance (*f*), which had a nearly quadrangular form, but was separable into two different masses, of which the outer was greyer and of an oval shape. From both of these the anterior nerve-roots (*g*) originated and escaped from the anterior and outer angle of the grey substance. Along the posterior half of the epithelial layer (*a*), its nucleated network was arranged in a connected series of arched radiations, which extended into the pyriform mass of grey substance on the same side (*b*). From this substance another very evident series of separate fibres ran directly forward to that part of the *anterior* grey substance (*f*) from which its nerve-roots chiefly arose. Neither these nor the arched fibres just mentioned as radiating from the epithelium could be seen so distinctly in the Sheep. Although the grey substance consisted of the several separate masses above described, yet there was but little diversity in the appearance of its structural elements. Its nuclei, generally, were rather smaller than in the section of the fœtal sheep represented in fig. 1.

The cylindrical column (*k*) in the centre of the body of the vertebra (*jj*), and corre-

* See Philosophical Transactions, 1859, Plate XXIII. figs. 34, 35, and 36.

sponding to the *chorda dorsalis* of fishes and reptiles, was at least five times as large in diameter as that of the Sheep, and somewhat different in the arrangement of its elementary parts. It consisted of a loose honeycomb structure with large vacant spaces, formed by a coarse network of fibres, with a nucleus at each point of their junction (see fig. 45, *a*, Plate XLVIII.). Around the cylinder, elongated nuclei giving off fibres in a circular direction were arranged in concentric layers.

In a fœtal sheep a little larger than that first examined, and measuring exactly 1 inch in length, a section of the spinal cord from the same region as before (the upper part of the lumbar enlargement) presented the appearances seen in fig. 3, Plate XLV. The canal, as a sword-shaped slit, extended behind-forward through nearly the whole of the grey substance. Immediately surrounding it was a bulbous or club-shaped layer of nuclei, with its bulbous end (*l*) posterior and reaching the surface in the middle line, but partially covered on each side by a portion of the posterior column (*c*). At this latter part it was less clearly defined, and gave off a process of grey substance, which extended outward and forward beneath the rest of the white column (*c*), and terminated in a rounded but imperfectly circumscribed mass (*b*). From about its middle to its anterior extremity the narrower portion of the club-shaped layer consisted of a nucleated meshwork of epithelium with an outwardly-radiating tendency; but on passing backward to the bulbous end, this appearance was confined to the wall of the canal, and moreover became less distinct, while at the same time it was gradually lost amongst the densely aggregated nuclei in the lateral part of the bulb.

The anterior grey substance presented nearly the same aspect as in the section represented in fig. 1. There was a very evident decussation, or crossing of fibres from the opposite roots of the nerves, in front of the canal; but, as in the last section, there was no anterior median fissure.

In the elements of the grey substance there was scarcely any perceptible advance in development. Some of the nuclei in the anterior masses seemed in a trifling degree to have increased in size, become more irregular in shape, and to be connected by a network which had rather more of the sponge-like arrangement.

The antero-lateral columns had somewhat increased in depth. Behind, where they joined the posterior columns, they were much shallower than elsewhere, and formed, on each side, the so-called lateral column (*h'*), which was sunk in a depression between the anterior and posterior grey substance.

The posterior white columns (*c*, *c*) were also deeper than in the previous sections. Behind, they were bevelled on to the exposed surface of the central club-shaped layer; and in front, where they joined and overlapped the lateral columns, they terminated in prominent but rounded edges, to which the posterior roots of the nerves (*d*) were attached.

There is every reason to believe that the fibres of the white columns are developed from the grey substance as prolongations of the network by which its nuclei are connected.

In fœtal sheep of exactly 2 inches in length, it was found that the different parts of the spinal cord already described had become more or less modified in form, size, and relative arrangement, that new parts had been superadded, and that the structural elements of the grey substance had undergone considerable alterations. Fig. 4, Plate XLV. represents a transverse section of the cord from the same region as before, viz. the upper part of the lumbar enlargement. Here we at once perceive that each lateral half of the grey substance is fashioned into very distinct anterior and posterior cornua (*f*, & *l b*), which are partially separated from their fellows of the opposite side by an anterior and a posterior median fissure (*m*, *n*), both of which were absent in the former sections, and now come into existence, as we shall presently see, as a *consequence* of the development of the cornua. We also observe that the anterior half of the central slit represented in the preceding figures has dilated into an oval canal (*o*), which is near the centre of the section. Moreover it will be seen that two new portions of the posterior white columns (*p*, *p*) have made their appearance on each side of the posterior median fissure. Let us now consider the course of the developmental growth by which these changes have been gradually effected. First, then, it may be remarked that in fig. 4 the anterior cornua are formed by a growth of the grey substance forward and inward, in front of the canal, from the imaginary line (*f*), which corresponds to the line of limit of the anterior grey substance (*f*) in fig. 3. The anterior white columns (*h*, *h*) extend in the same direction around the growing ends of the cornua, until only a narrow space or fissure is left between their inner borders in the mesial line. In this way is formed the anterior median fissure (*m*) in front of the commissure, which projects into it as a conical process. During these changes in the anterior part of the cord, the posterior grey substance (*l b*, fig. 3) grows obliquely outward and backward (*l b*, fig. 4); while its anterior angle (at *b*) becomes further removed from the posterior angle of the anterior cornu (*f'*), and is separated from it by a broader and deeper indentation, which is the rudiment of the neck or cervix cornu posterioris. This space or indentation is filled up and overlaid with the lateral column (*h'*), which has reached the level of the posterior column (*c*) and assumed a convex surface. This so-called lateral column differs from the rest of the white substance in being subdivided into a much greater number of small but separate fasciculi of various shapes, by means of a remarkable system of radiating fibres which proceed both from the grey substance between the cornua and the epithelium surrounding the canal. A radiation of fibres, however, but of much less extent, takes place from the whole circumference of the grey substance.

At the commencement of these changes, the central fissure or canal represented in fig. 3 reaches the surface of the posterior grey substance. The growth of this substance is then continued not only backward, but *outward*, or divergent from the mesial line, while in the intervening angular and gradually increasing space between it and this line (fig. 4, *n*) there are developed on each side two new pyramidal columns of longitudinal fibres (*p*, *p'*), which increase in depth in a corresponding proportion. Of these, the outer one (*p*), which is much the larger, rests on the back of the cornu, over which it ultimately

blends with the *outer* portion (*e*) of the posterior column previously developed. The inner and smaller column (*p'*) is in general more conspicuous and distinct in the dorsal and cervical than in the lumbar region, as shown in figs. 5, 6, & 7. The opening of the original canal or slit between these additional columns constitutes the posterior median fissure (*n*), which is now occupied by blood-vessels and pia mater in connexion with radiating fibres from the central epithelial layer.

We see, then, that the direction taken by the developmental growth of the posterior grey substance is just the reverse of that which is followed by the anterior. The changes which occur in the former, and the consequent production of new columns, have much resemblance to some of those that take place in the upper part of the cord during its transition and development into the medulla oblongata. In the course of those changes the central canal retreats further and further to the posterior part of the medulla, until at length it opens on the surface in the form of the fourth ventricle. In a corresponding proportion the posterior cornua diverge, while from their roots on each side of the mesial line the posterior pyramid is developed *. The cases, however, are not exactly parallel.

Returning to the interior of the grey substance, we find that a variety of changes, more or less important, have occurred,—first, in the disposition and destination of some of its parts; secondly, in the structure and arrangement of its constituent elements. First, then, we may observe that the club-shaped layer surrounding the central fissure or canal, as represented at *l*, fig. 3, has lost its defined outline and become very much diffused. Behind the oval canal, on each side of the mesial line (at *q q*, fig. 4), it forms the inner half of the cervix cornu posterioris, which subsequently contains the posterior vesicular column, or nucleus of the cervix. Hitherto, however, it consists only of a closely aggregated mass of nuclei, which become gradually more diffused on its outer side, where it joins the rest of the grey substance. Passing backward and outward and then forward in the direction *l b*, as an arched layer near the posterior border of the cornu, it terminates in the dark mass (*b*) within its outer angle or point. In the space between this arched layer and the posterior border of the cornu, the nuclei are less closely aggregated, and thus constitute, with their intervening network, a paler lamina (*r r*), which is the rudiment of the *gelatinous* substance. In the adult cord, as I showed on former occasions, the space occupied by the above-described arched layer of nuclei contains numerous bundles of nerve-fibres continuous with the posterior roots. On its inner side, near the centre of the cornu, there is a somewhat paler space, which is continued forward and outward, in a curve, to the border of the grey substance at the bottom of the lateral column. This is more conspicuous in the dorsal region, as shown in figs. 5 & 6.

On tracing the club-shaped layer forward along the side of the median line, we observe that its outer part has lost the defined outline which it possessed in section 3,

* See my memoir on the "Medulla Oblongata," Philosophical Transactions, 1858, Plate XII. figs. 13 & 14, *b* Plate XIII. fig. 16; Plate XIV.; and Plate XV. fig. 19.

and has gradually blended with the anterior grey substance; while its inner border forms the epithelial layer (*s*) surrounding the central canal. Along the *sides* of the canal, the epithelium, as regards its constituent elements, differs but little in appearance from the rest of the grey substance. The only apparent differences are, that its nuclei are less closely aggregated; that the fibres radiating through their interspaces from the verge of the canal, and which are thicker, are consequently *seen* to be more continuous and branched; and that a few of its nuclei are larger, while others are more elongated or fusiform at right angles to the axis of the canal. Nor is it bounded externally by any definite line, but is continuous, as a nucleated network, with that of the anterior cornu. From the posterior margin of the elliptical canal its radiating fibres extend outward and backward into the posterior cornua, and directly backward between them into the posterior median fissure. In *front* of the canal, however, the epithelium has a somewhat different arrangement. At this part it forms a deeper and more distinct layer, containing more of the fusiform nuclei, which are elongated in a direction forward, and terminate at each extremity in a fibre. At the sides of this layer the nuclei with their fibres are curved inward, but become progressively straighter as they approach the middle line (see figs. 4 & 8). Posteriorly their processes or fibres are thicker, and attached by their extremities to the margin of the canal; while anteriorly they converge across the anterior commissure, as a conical network, into the anterior median fissure, where they become directly continuous with the fibres of the pia mater and connective tissue enveloping numerous blood-vessels and derived from the circumference of the cord (*m*, figs. 4 & 8). In many cases the epithelium in *front* of the canal differs but little in appearance from the rest of the layer, except that the principal fibres of the network converge forward to join the process of pia mater in the anterior median fissure. In such cases it has a general resemblance to that seen in fig. 9, Plate XLV., which exactly represents a portion of the canal and surrounding grey substance of a human fœtus of nine weeks, magnified 420 diameters. It was taken from the same fœtus as the section represented in fig. 8, Plate XLVI. *o* is the anterior part of the canal; *s*, *s*, between the canal and the outer line, is the layer of epithelium, which on each side, however, is seen to be gradually continuous with the anterior grey substance, *f*; while in front it terminates in a conical network of connective tissue interspersed with nuclei, and continuous (at *m*) with the pia mater of the surface.

I have next to show that the elements of the grey substance, which in fig. 3 were nearly uniformly alike, have in fig. 4 become more or less modified both in structure and arrangement. In fig. 3 every nucleus had a plain or smooth appearance, without any trace of granular contents or of a distinct enveloping membrane. In fig. 4, however, both these modifications of structure had taken place; and although the observation of this fine distinction might seem to be trivial and unimportant, it will nevertheless be seen, as we proceed, to be well worthy of attention. It was also observed that in section 3 the nuclei were very nearly of the same size in all parts of the grey substance. In section 4, however, those of the anterior grey substance had everywhere

increased in diameter; while those of the posterior grey substance, as far forward as the posterior level of the canal, had scarcely, if at all, advanced in size. In all the darker parts of the latter they were still very closely aggregated, but less so than in fig. 3; so that the network of fibres by which they were connected was conspicuous in a corresponding proportion. Fig. 10, *b*, Plate XLV., represents some of the nuclei and their connecting fibres, from the arched layer (*l b*) of the posterior cornu in fig. 4, magnified 670 diameters*. In the section, however, although it was exceedingly thin, the nuclei were rather more crowded in that part; but exactly the same appearance is presented where a very thin portion has been shaved to an edge.

Throughout the whole of the *anterior* grey substance the average size of the nuclei is about twice as great as in the *posterior* grey substance, and therefore about twice as great as in every part of section 3. Their increase in diameter begins rather abruptly near the posterior level of the oval canal. They have also become more granular, more distinctly circumscribed by well-defined walls, and lie at greater distances from each other. The tissue which supports them has still a reticular structure, but is looser, more open, and in the central portion of the cornu consists of a sponge-like network of coarser fibres, which are more or less granular and connected with the nuclei by irregular aggregations of granules. Fig. 12, at *v*, Plate XLVII., is a faithful representation of this peculiar arrangement, which can be more intelligibly represented than described. In the middle of the cornu, where it is traversed by the central fibres of the anterior nerve-roots, as they run directly backward, the structure has very much the appearance delineated in fig. 11, Plate XLVII. But in the antero-lateral parts of the cornu (*w*, *w'*, figs. 4 & 7, Plate XLV.), where the groups of large nerve-cells are developed, it has a kind of honeycomb arrangement in the form of circular or somewhat irregular cavities or cells, which are large, but variable in diameter, and frequently in close apposition, but often separated by angular interspaces containing each a nucleus encrusted with granules. Fig. 12, *x x*, Plate XLVII. is a very exact representation of a portion of the outer or lateral group (*w'*, fig. 7, Plate XLV.). The walls of the cavities and the granular network are directly connected with the tissue of the antero-lateral white columns at *y*, *y'*. Within each cavity is a nucleus, which is sometimes in or near the centre, sometimes more excentric, and sometimes close to the wall. The nucleus is imbedded in granules, which are generally seen to connect it to the wall, and which in some instances occupy the whole, in others only part of the cell; in the latter cases they aggregate in a variety of forms†.

Within the posterior angle or shoulder of the anterior cornu is a remarkable dark and nearly triangular group of nuclei (fig. 4, *f'*, Plate XLV.), which differ from the rest only in being rather larger, and more closely aggregated.

The roots of the nerves may be very distinctly traced into the grey substance (see

* By some mistake this figure is marked in the Plate as ×420 diameters.

† The separation of the granular masses from their cell-walls, and the stellate form which they sometimes assume, seem due to the action of the chromic acid.

fig. 8, Plate XLVI.). The anterior roots (*g*) are attached to the anterior column, which they traverse transversely inward to reach the anterior cornu (*f*), within which their fibres diverge and cross each other in different directions. A large number proceed backward along the lateral part of the cornu, some of them running in succession outward to the lateral column (*k*), while the rest reach the triangular group of nuclei just pointed out, within the posterior angle of the cornu. Another set of fibres run more directly backward, through the central part of the grey substance (*f*), where they join in the general network, and appear as represented in fig. 11, Plate XLVII.; while some curve inward to decussate, in front of the canal, with their fellows of the opposite side, in company with others proceeding forward and inward around the canal from the *posterior* grey substance. (See also fig. 3, Plate XLV.)

The posterior roots (fig. 8, *d*, Plate XLVI.) have no immediate connexion with the lateral columns, and are attached solely to the posterior, through which they diverge in a direction backward and inward to reach the grey substance (*l b*). On entering this substance many of them evidently become finer by subdivision, and contribute to form the network by which the nuclei are connected. Fig. 10, Plate XLV. is a faithful representation of a very thin transverse section near the extremity of the posterior cornu, through which the roots (*d*) are entering; at *b* they are seen to become continuous with the general network. In the same way many of the fibres of the posterior columns are connected with nuclei of the grey substance. (See fig. 15, I, Plate XLVII.)

In fœtal sheep of 3 and 4 inches in length, there was no remarkable alteration in the shape and disposition of the grey and white substances in the region corresponding to fig. 4; nor was there any great difference in the appearance or arrangement of the constituent elements. Fig. 13, Plate XLVI., represents a transverse section of one, and part of the other, lateral half of the spinal cord, near the middle of the lumbar enlargement, of a fœtal sheep, 4 inches long; and fig. 14 shows a similar section of the middle of the lumbar enlargement of a fœtal ox, 5 inches long. Here we see that nearly one-half of the posterior grey substance still consists of a dark layer of closely aggregated nuclei, which differ but little in size and general appearance from those of section 4, Plate XLV. This dark layer constitutes the *caput* cornu posterioris. Fig. 15, I, Plate XLVII. is a longitudinal section of it near its outer border, or the posterior extremity of the cornu, where it is overlaid and crossed in different directions by the decussating fibres of the white column. As the posterior (*l b*, fig. 14) merges into the anterior grey substance (*f*), the nuclei become larger, while the network which supports them becomes coarser and looser (II, fig. 15, Plate XLVII.). In the posterior part of the section, the very irregular and granular meshwork of fibres appears to extend nearly equally in all directions; but towards the anterior part (opposite II) the meshes have a tendency to elongate in a direction forward; while many of the nuclei are elongated in the same direction, and have tapering granular masses extending from their ends. These latter appearances, however, are more conspicuous on the inner side of the cornu, nearer the median line. On proceeding forward, the network assumes the peculiar

honeycomb structure already observed in section 4, and represented at *x*, fig. 12, Plate XLVII. Here, however, the layer is deeper, but variable in depth. Fig. 15, III, Plate XLVII. is a portion of a longitudinal section, behind-forward, through this layer of large cells of the anterior cornu (*w w*, fig. 14, Plate XLVI.). It will be remarked that these more or less globular cells are closely grouped, and frequently in actual contact; that in many instances they are seen to be filled with the granular material surrounding their nuclei; and that the nuclei themselves are sometimes larger than those in other parts of the anterior grey substance, and contain each either one large globular nucleolus or two. With the general network of this layer the anterior nerve-roots may be seen to be continuous.

In fœtal sheep of 6, 7, and 8 inches in length, further changes were observed to take place in the grey substance, but they were limited chiefly to its posterior and middle portions. In the *caput* cornu posterioris, the nuclei, although still aggregated in vast numbers, were comparatively less numerous and more widely separated from each other than in fig. 15, and somewhat larger; the network of fibres by which they were connected was also coarser and looser; while a complete system of transverse, longitudinal, and oblique nerve-fibres were very readily distinguishable.

In the middle portion of the grey substance, that is, between the caput cornu (*l b*, fig. 13, Plate XLVI.) and the groups of large nerve-cells (*w*, *w'*), the coarse network already described and represented in fig. 15, II, Plate XLVII. was now interspersed with a great number of cells, which differed from each other both in size and shape (fig. 16, Plate XLVII.). The majority were fusiform in a direction before-backward, and either more or less wavy and sigmoid, or perfectly straight, with processes which extended occasionally to an amazing distance. In some cases, as at *a*, fig. 16, a fusiform cell was bent into the shape of a crescent, and formed part of the circumference of an oval or circular space. In other cases it was converted into a triangle by giving off two processes from one end, which became broader, and embraced, as before, part of the circumference of an open space (*b*, fig. 16). In many of these cells, especially of the smaller kind, the nuclei were only faintly, or not at all, observable.

The groups of large nerve-cells (*w*, *w'*) had undergone scarcely any appreciable change, and presented nearly the appearances represented at III, fig. 15.

With regard to the changes which ensue in the structure of the cord on approaching the period of birth, I shall confine my remarks chiefly to those particular points which relate to the development of its constituent elements. During these successive changes, the *gelatinous substance* becomes more and more conspicuous as a distinct lamina around the end of the caput cornu. Along its margin the peculiar nerve-cells observable in the adult are gradually developed, after the manner of those already described in the middle of the grey substance (fig. 16, Plate XLVII.); while its arciform, transverse, oblique and longitudinal fibres increase in number in a corresponding proportion. Coincident with this development of the gelatinous substance, the nuclei in the dark and inner part of the *caput* cornu become less numerous, while its transversely-radiating, longitudinal,

and variously-oblique fibres, continuous with roots of nerves, increase in a corresponding proportion and pursue a more definite course. But even at an advanced period of utero-gestation (at the fifth month, for instance, in the human fœtus) the *caput* cornu is still very thickly crowded with nuclei, and presents an opaque and uniformly dark mass, like that of the fœtal ox of 5 inches long, represented in fig. 14, Plate XLVI. By the end of the *sixth* month, however, it is much less opaque, and contains a much smaller proportion of nuclei, but a correspondingly large proportion of fibres running in the directions already indicated. Fig. 40, Plate XLVIII. represents, under a low power, a transverse section of one lateral half of the grey and white substances of the cord from the upper part of the lumbar enlargement of a human fœtus of six months*. Here the *caput* cornu posterioris (*l b*) is at once distinguishable from the *cervix*, not only by its bulbous expansion, but also by its much darker colour. The gelatinous substance, however, and arciform fibres are not very strongly marked, but were readily detected under high magnifying-powers. In the larger and darker portion of the caput, the nuclei were imbedded in a fine granular network, and were most numerous at its sides, particularly its outer side. Amongst this network were the longitudinal and oblique fibres, to which in the adult cord the opacity of this part is chiefly due. The majority of the nuclei were round, but some were oval, and a few had an angular form. They were finely granular, were enclosed in distinct envelopes, and differed from each other in size. Their average diameter was rather below that of the blood-globules of the same fœtus. Scattered irregularly amongst these were a few others, which, in addition to the fine granules, contained each a larger, central and globular nucleolus. These latter nuclei were identical in appearance with the nuclei of the larger nerve-cells.

By referring to the same figure (40), it will be seen that each inner half of the cervix cornu (*q*) is occupied and rendered convex by a remarkable group of nucleated cells, which I formerly described very fully under the name of the posterior vesicular column†. In this region of the cord (the upper part of the lumbar enlargement), not only are these columns larger than in any other region, but the cells which they contain are for the most part of the largest description, and similar in appearance to those of the *anterior* cornu: but their development is somewhat later. In the human fœtus, at the sixth month, however, they are perfectly developed, and assume a variety of stellate forms, with processes that extend in all directions. They are closely invested by a thin

* Through the kindness of Mr. HATHERLY, of Belgravia South, I was fortunate enough to obtain this fine male fœtus within about an hour after death. The brain and spinal cord were immediately removed and hardened in the most gradual and careful manner by immersion, first, in an exceedingly weak solution of bichromate of potash, then in stronger solutions of the same salt, and finally in a solution of chromic acid. The preparations, of which a series of representations are given in Plate XLVIII., are the most beautiful that I have ever succeeded in obtaining from the *human fœtus*. I must also acknowledge my obligations to Mr. R. DUNN, of Norfolk Street, Mr. WHITNEY, of Westminster, Mr. PAINTER, of Westminster, and Mr. HUNT, of South Belgravia, for their kindness in providing me with fœtuses.

† Probably a better term for this column would be the nucleus of the cervix cornu—*nucleus cervicis cornu*.

sheath or envelope, which is prolonged on to the processes and connected with the intervening reticular tissue. It is beyond all doubt (for it was distinctly seen in preparations of this fœtus) that many, at least, of the processes, by repeated subdivision, become continuous with the fine network of this intervening tissue. See fig. 17, Plate XLVII.*

In the same fœtus the *tractus intermedio-lateralis*, or tract of grey substance (*t*, figs. 41, 42 & 43, Plate XLVIII.) which projects into the lateral column between the anterior and posterior cornua, was in a nearly complete state of formation.

The epithelium, also, surrounding the canal was completely developed, and on no occasion in the *human* cord have I seen it so perfect and beautiful. In the adult human cord it is very difficult to obtain a good view of the exact form and arrangement of its constituent elements, which are often, especially in the cervical region, confusedly heaped together in a mass that entirely fills up the canal†. In the *fœtal* cord, however, the canal is larger, the epithelial layer is deeper, and its elements in general are more uniformly arranged. In the case now under consideration these elements were more than usually distinct. In some regions of the cord they were exactly alike throughout the whole circumference of the layer. In such regions they consisted partly of oval, and partly of still more elongated nuclei or cells, which gave off a process from each extremity, and were arranged with their longer axes at right angles to the axis of the canal. The *nuclei*, however, were placed at *different distances from the canal*, and were so disposed as to lie in nearly close apposition, and form a compact stratum. Their *central* processes, which reached the *inner* margin of the layer, were consequently of *different lengths*; and the length of these processes, in general, was inversely proportional to their thickness. Here and there between the rest of the nuclei, narrow interspaces were occupied by remarkably slender and fusiform bodies, of which the tapering ends reached the verge of the canal, without the intervention, apparently, of any distinct processes. At their *peripheral* or outer ends all these nuclei tapered into fine fibres which crossed each other in every direction, and frequently divided into smaller branches, to be continuous with the network surrounding the epithelial layer. In the lumbar region of the cord the nuclei were *not* exactly alike around the whole circumference of the canal. In the anterior third of the layer they were in every respect similar to those which I have just described; and at the front of the canal, the fibres proceeding from their peripheral ends were seen to cross the commissure, and become directly continuous with the process of pia mater within the anterior fissure. Frequently this process consisted almost entirely of blood-vessels containing numerous well-preserved globules, and at the bottom of the

* This statement is confirmatory of the descriptions which I first gave of the ramifications of the processes of the nerve-cells of the spinal cord.—Philosophical Transactions, 1851, p. 614.

† On a former occasion (Phil. Trans. 1850, Part I. p. 455, and Plate XXII. fig. 55) I showed that the canal in the human cord is sometimes double, or rather that two secondary canals, as it were, are hollowed through the mass of epithelium just mentioned. The same fact has since been made the subject of a paper by Dr. Joh. Wagner, in Reichert-Dubois's Archiv für Anat. &c. 1861, p. 735. Even in the fourth ventricle, at the calamus scriptorius, in Man I have frequently found on the surface a kind of short supplementary canal formed by a double layer of epithelium enclosing a narrow space.

fissure it gave off a brush-like radiation of fibres that were continuous with those of the epithelium. In other sections, blood-vessels from the same process extended right and left, as well as backward and around the canal. Some of the fibres from the epithelial cells on each side of the front layer, after crossing the anterior commissure, penetrated the anterior white columns, at the sides of the fissure, and were lost in the tissue between its longitudinal fibres. Behind, a narrower portion of the epithelial layer was composed of the same kind of elements as those which were found in front; and in a similar way fibres proceeding from their peripheral ends converged *backward*, to be continuous with blood-vessels and pia mater in the *posterior* median fissure. Other fibres, also, from the same source could be traced into the posterior white columns. Around the remaining portion of the canal the epithelial layer was narrower and somewhat different in structure. It consisted, for the most part, of round and of rather oval nuclei, irregularly disposed, and in connexion with the fibres on the outside of the layer. These nuclei, like the others just described, were finely granular, and in every way similar to a multitude of those which are scattered through the grey substance, and, as I shall presently show, through the tissue between the fibres of the white substance*.

The large nerve-cells of the anterior cornu had assumed the shape and general appearance which they present in the adult cord. Like those of the cervix cornu posterioris,

* This description of the epithelium in the human fœtus has a general resemblance to that which I gave of the same structure in the full-grown ox (Phil. Trans. 1859, p. 455, Plate XXII. fig. 53); but I have entered more particularly into details in the present case, on account of the close resemblance of the *oval* cells to the "olfactory cells" of the olfactory mucous membrane as first described by Schultze in the Frog and Pike. It is believed by Schultze and others, that the processes of these "olfactory-cells" are directly continuous with fine fibres of the olfactory nerves. Such a connexion, however, has never, so far as I am aware, been actually *seen*. I have myself traced these nerve-fibres quite into the epithelial layer, but have not hitherto quite satisfied myself of their actual termination. Six years ago I showed that beneath the epithelium of the pharyngeal sac of the common earth-worm, a ganglionic plexus of nerves terminates in a network of single nucleated fibres, resembling in form a capillary network (Proc. Royal Soc. Jan. 1857, No. 24. vol. viii.). It is true that Axel Key (Archiv für Anat. &c. 1861, p. 329) has described and figured in the tongue of the Frog, a remarkably conspicuous communication between nerve-fibres and cells which correspond to those of Schultze. But no such communication was observed either by Billroth or Hoyer (Archiv für Anat. &c. 1858 & 1859) in the same organ. On the fibres proceeding from the "olfactory cells" of Schultze, there are slight granular dilatations, which I have found most remarkable in the Pike. On the fine fibres which surround the canal in the human fœtus, as above described, and with which the processes of the oval epithelial cells are connected, I have also observed exceedingly minute dilatations. These fibres, as already stated, are evidently continuous, and identical in appearance with the fine fibres of the pia mater on the outside of the cord. Without, therefore, denying the *possible* continuity of the "olfactory cells" with true nerve-fibres, we must be so much the more cautious in admitting their *actual* continuity as an anatomical fact, until confirmed by actual *observation*. That the fibrous structure immediately surrounding the spinal canal is of the nature of connective tissue, was first maintained by myself (Phil. Trans. 1851) in opposition to Stilling, who described it (together with the epithelium, which he had not detected) as a "circular commissure" composed of *grey* nerve-fibres. In the human brain, also, the processes of the epithelium which extends from the aqueduct of Sylvius along the under surface of the posterior commissure, have clearly been seen by myself to pass through fissures in that commissure, to the pia mater on its opposite surface (Proceedings of Royal Society for June 20, 1861).

they were enveloped in delicate sheaths, which, however, were quite distinct from, although in connexion with, the surrounding reticular tissue (see figs. 12 & 15, Plate XLVII.). Many of their processes also were very clearly seen to subdivide, or to break up suddenly, into a multitude of fine branches to form part of the intervening network†.

I shall conclude my remarks on the development of the cord in the human and mammalian fœtus, by a few observations on the development of its nerve-fibres. In a very young fœtus it is difficult to obtain a satisfactory view of isolated nerve-fibres, and to detect the way in which their formation commences. According to my own opportunities of observation, they are not developed from nucleated cells, but rather by the extension of finely granular substance from round and oval nuclei. On this point, however, I cannot at present speak with confidence, and therefore leave it open for further inquiry. In the early stages—for instance, in a fœtal sheep, or human fœtus from 1 to 2 inches long—the fibres, in a *fresh state*, consisted of most delicately granular and nucleated bands, without any sharpness of outline or appearance of separate border. But the nuclei were far from being numerous, either in the nerves or in the white columns of the cord. In fig. 8, Plate XLVI. their average number is shown in the white columns of the left side, in a human fœtus of about nine weeks. As development, however, advances, their number increases considerably, while the fibres to which they belong acquire a more sharply defined outline or border, which in some parts of its course appears darker and thicker than in others. In fig. 9+, Plate XLV., on the left, is an exact representation of a separate fibre in a fresh and unprepared state, from the sciatic nerve of a human fœtus of four months, magnified 670 diameters; and in the same figure, on the right, is represented the appearance of several such fibres as they lie side by side in a bundle. Fig. 18, Plate XLVII. shows a small portion of a transverse section of the posterior white columns of a human fœtus of five months, magnified 670 diameters. When compared with the same parts in fig. 8, Plate XLVI., which is magnified only 50 diameters, it shows how much the nuclei have increased in number. Some of these nuclei belong to the sheaths of the nerve-fibres, others to the tissue by which their sheaths are connected. As the period of birth approaches, they are again reduced in number; but even in the adult cord, as I showed on a former occasion, they are scattered at intervals between the fibres of all the white columns. In structure they are altogether similar to the nuclei of the fœtal epithelium above described, and differ from them only in having a somewhat less average diameter.

With regard to the development of the spinal cord in Birds, I need dwell only on those particulars in which it differs from that in Man and Mammals. Fig. 19, Plate XLVII. shows the appearance of the grey and white substance in a transverse

† I have described and figured a similar ramification of the processes of the cells around the base of the peduncle of the olfactory bulb, and in the anterior perforated space, and have frequently observed the same appearance in the convolutions of the cerebral hemispheres. (See Zeitschrift für Wissensch. Zoologie, Bd. xi. Hft. 1. Taf. v. fig. 6.)

section of the upper part of the sacral enlargement of the chick, on the fifth day of incubation. The central dark layer (*a*) surrounding the canal is still uncovered by the posterior columns (*c*, *c*), and forms the posterior surface. The grey substance hitherto is not divided into distinct cornua; there is no trace of a posterior median fissure, and only the first rudiments of an anterior (*m*). In the course of four days we find that rapid and remarkable progress has been made in developmental growth. Fig. 20, Plate XVII. represents the appearances in a transverse section of the same part, at the end of the ninth day of incubation. By a succession of changes similar to those that have been described in the fœtal sheep, both the anterior and posterior cornua have become fully developed, with corresponding median fissures. In each anterior cornu (*f*) is a thick cylindrical column of large nerve-cells. These cells, however, for the most part, differ both in shape and mode of formation, from those that are found in the corresponding part of the human and mammalian fœtus. The majority are fusiform from before backward, and continuous with the antero-posterior fibres which reach the posterior cornu. They are not formed within large round and oval spaces with thick walls, like those already described in the mammal, but grow side by side in close apposition by the extension of substance from the ends of their nuclei, apparently after the manner of those in the central part of the grey substance of the Sheep and Ox, represented in fig. 16, Plate XLVII. Besides their antero-posterior processes, they send off others both outward and inward. The middle portion of the grey substance between this vesicular group and the posterior cornu contains a few isolated cells of the same kind.

The antero-lateral white columns (*h*, *h'*) have increased considerably in area, and the anterior median fissure between them is much deeper, while the canal (*o*) is reduced in size and limited to the centre of the section. The caput cornu posterioris (*l b*), on each side, consists of a dark mass of closely aggregated nuclei, which are smaller than those in any other part of the grey substance. It is entirely covered by the posterior white column (*c p*), which, however, does not extend along the inner side of the cervix (*q*). The space between the cervix cornu (*q*) of one side and that of the other, and which, in the corresponding part of the adult cord of both the bird and mammal, is occupied by the inner and deep portions of the posterior columns, is now filled up by a bell-shaped mass of connective tissue (*n'*), which consists of a loose network of fibres connected at intervals with nuclei. The fibres of this tissue are also directly continuous with the connective tissue of the inner part (*p*) of the posterior white column, and with the network in the cervix cornu (*q*), along the inner border; but its fibres are coarser, and its nuclei are larger. Its deep portion, which is divided by a central raphè, forms the posterior wall of the canal (*o*), and *constitutes its epithelium* on that side; while its superficial portion extends on each side over the posterior white column (*p*), and is connected at its convex surface with the *pia mater* which surrounds the cord. In the lower part of the sacral enlargement (fig. 21, Plate XLVII.), the cervix cornu is united along the middle line with its fellow of the opposite side, and forms with it a single mass; so that only the extremities of the cornua surrounded by the posterior columns remain

apart from each other. Between these the space *n*, which here represents the posterior median fissure, is much shallower and narrower than in fig. 20, and widely separated from the central canal by the coalescence of the cervix (*q*) of each side. The loose and nucleated tissue (*n'*), however, with which it is filled is still connected, across this coalesced grey substance, with a number of fibres radiating from the epithelium around the posterior wall of the canal (*o*). On ascending the sacral enlargement, the posterior cornua become more and more deeply separated, until the division reaches the canal. Fig. 22 represents a transverse section about midway between sections 20 and 21. Here the space *n* between the cornua has, in section, the form of a deep cylinder filled with the loose nucleated tissue, of which the deepest portion itself constitutes the epithelium around the posterior wall of the canal, instead of being only connected with it, as shown in fig. 21, by a number of radiating fibres. As development advances, the inner part (*p*, fig. 20) of the posterior column gradually extends over the side of the cervix cornu (*q*), and replaces a corresponding proportion of the nucleated tissue (*n'*), until it reaches the median raphè at the back of the canal. On approaching the *middle* of the sacral enlargement, the entire lateral halves of the grey substance are more widely removed from each other, and joined only by the *anterior* commissure; for the *posterior* commissure has no existence. At the same time the canal is lengthened in a lateral direction, and opens behind, through the raphè or median fissure, to form the rhomboidal sinus, which is filled up with the remaining nucleated tissue continuous with the pia mater of the surface*.

I have now to describe the development of the intervertebral ganglia.

In the young fœtus, the first thing that strikes the observer on looking at these ganglia, is their enormous size in comparison with the diameter of the spinal cord. Fig. 8, *e*, *e*, Plate XLVI. represents them as seen in a transverse section of the vertebral column of a human fœtus of 9 weeks. In this section each ganglion appears nearly as large as the entire lateral half of the grey substance of the cord itself. It is closely invested by a fibrous sheath, which is prolonged on to the nerve-roots, and is continuous with the surrounding connective tissue, as well as with the denser nucleated tissue that constitutes the lamina (*z*) of the vertebra. In a fœtal sheep of 1 inch in length, the ganglion consisted of a mass of closely aggregated nuclei or cells, connected together by a network of fibres. Fig. 23, *a*, Plate XLVII. represents a small portion magnified 420 diameters. The fibres connecting the nuclei or cells were continuous on the one hand with the nerve-roots which entered the ganglion, and on the other hand with the surrounding connective tissue. Their course was most conspicuous in an antero-posterior direction—that is, in the direction in which the nerve-roots spread through the ganglion. The nuclei or cells were about the same size as those of the grey substance of the cord to which they belonged, but were rather more varied in shape. Like them also, at this period of development, they had a plain and smooth appearance, without any traces of granular contents and of distinct enveloping membranes.

* Compare my figs. 34, 35, & 36, from the adult bird, Philosophical Transactions, 1859, Plate XXIII.

In a fœtal sheep of about 1¾ inch long, it was found that a considerable proportion of the nuclei or cells had increased in size, but in a variable degree. Many of them were twice as large as those in the fœtus of 1 inch, while others were still about the same size. Fig. 24, Plate XLVII. represents a small portion of the ganglion as seen in a transverse section of the spinal column and cord—that is, in the direction in which the nerve-roots enter and leave it. A great number of the nuclei or cells were also more diversified in shape; they were round, oval, triangular, irregular in outline, and variously stellate. By processes of different lengths and degrees of fineness all of them were connected with each other, as well as with fibres of the nerve-roots; and at the circumference of the ganglion this common network was continuous with the surrounding nucleated connective tissue, as at *b*, fig. 23, which represents a portion of the tissue connecting the outer part of the ganglion (*a*) with the lamina of the vertebra. Many of the round and oval nuclei evidently belonged to the connective tissue, and some few to the nerve-fibres which spread through the structure. The nerve-cells, although enlarged, had a smooth homogeneous aspect, and presented scarcely any traces of internal nuclei. Here and there, however, a faintly granular appearance was visible through their surface; and in some cases, as at *a*, fig. 24, a rounded but imperfectly-defined body, resembling an indistinct nucleus, might also be observed.

As development advanced, considerable changes were observed to take place in the appearance of the ganglion. At first, the principal changes consisted in an increase in the size and granular structure of a large number of the cells, while their nuclei remained still indistinct (see fig. 24*). Soon after, however, a striking alteration ensued both in the structure and form of the cells: fig. 25 represents a portion of the ganglion of a fœtal sheep, about 3 inches long, transformed from those just seen in fig. 24*. Here the nuclei in the cells are large, well-defined, round or oval, and contain one, two, and in some instances three globular nucleoli, surrounded by numerous granules. The cells to which they belong vary considerably both in size and shape. The majority, however, are perfectly pyriform or cup-shaped, their tapering ends pointing in different directions, while the broader end of each is occupied, or as it were closed, by its nucleus. According to the position in which they lie, and their different degrees of foreshortening, in reference to the observer, they appear either round, oval or pyriform. Sometimes several of them lie side by side in a similar position, and are continuous by their tapering ends with a corresponding series of branches from one nerve-fibre. Lodged in the spaces between them are a number of small nuclei, of an angular, oval, or elongated form, and resembling those which belong to the sheath of the ganglion (see figs. 25 & 28). When exceedingly thin sections were very carefully examined under a sufficient magnifying-power, it might sometimes be observed that the nerve-fibres, in their course through the ganglion, divided into branches, which became continuous with the processes of the cells; and when the section was carefully broken up into minute fragments by means of fine needles, these appearances were found to be universal. The nerve-fibres were then frequently seen to consist of bundles of delicate fibrillæ, each of

which separated in succession from the rest to be connected with one of the nerve-cells. Fig. 26, Plate XLVII. is an exact representation of a thick fibre giving off a short branch, which immediately subdivided into two and perhaps other fine filaments, to join a corresponding number of cells. The lower and broken end of the fibre seemed to be split up into its constituent parts, and resembled the hairs of a brush. Very frequently a series of pyriform cells, in close apposition, but one in advance of the other, were arranged in a compact group around a common fibre, with a fibril of which each was connected by its tapering end. Fig. 27 represents part of such a group, magnified 420 diameters. The connecting fibrils were of different lengths, and sometimes so short that the small end of the cell seemed to arise from the fibre itself. Where the relative position of the cells forming a compact group is less regular, we have the appearance represented in fig. 28. Through such a group the nerve-fibres pursue a more or less tortuous course, giving off branches or their component fibrils in succession, and in all directions, to the cells between which they pass. In fig. 29, for example, a fibre, after giving off fibrils to be connected with the smaller ends of the two uppermost cells, continued its course between them to be connected by a fibril with the next cell, along the sides of which two other branches ran in a similar way until they reached the points of other cells; and so on in different directions and planes. Between the upper and lower ends of the figure the cells were broken off, and exposed the fibre and its short branches.

When separated from the group, a large number of the cells seemed to have scarcely any investment that might be called a distinct cell-wall; but still they were frequently more or less covered by a shaggy layer of delicate fibres (a, a', fig. 30, Plate XLVIII.), by which in their natural position they appeared to be connected. This investment seemed to be an extension from the surface of the fibres or processes with which the cells were continuous, and occasionally entangled a small nucleus (a', fig. 30). In some instances, as at b, it assumed the appearance of a thin, loose, and delicate sheath; while in others, as at c, it formed a more compact investment, to which the nuclei were more closely adherent.

As development progressed the cells somewhat enlarged, while their walls increased in thickness, and, like the nerve-fibres, were studded with an increasing number of small nuclei. Fig. 31, Plate XLVIII. shows a portion of one of the intervertebral ganglia of a fœtal sheep, 8 inches long, magnified 420 diameters. Many of the cells, which had a globular appearance in their natural positions, were found to be pyriform when separated by dissection. Their walls were evidently prolongations from the surfaces of the nerve-fibres; the nuclei on the former were in every respect similar to those on the latter; and in both cases their number increased in the same proportion. Sometimes a nucleus was found at the point where a fibre was continuous with a cell; so that it was impossible to say whether it belonged to the one or the other. Fig. 32 represents a group of cells from the anterior part of an intervertebral ganglion of the chick, on the ninth day of incubation, at the point where the nerve-fibres are escaping to join the anterior roots. The

free surfaces of the walls have a shaggy structure consisting of fine fibres, by which they are connected with the walls of their neighbours, and apparently with the nucleated investment of the nerve-fibres which run between them*. Sometimes, in consequence probably of the action of the chromic acid, the cell-wall is removed to a little distance from the surface of the contained cell, but is still connected with it by fine fibres or processes. Now in the case of the large nerve-cells of the spinal cord, like those represented in fig. 12, *x x*, the thick cell-walls, as development advances, form part of the surrounding reticular tissue, with which the surface of the contained cells, still retaining a thin investment, is in a similar way connected by processes. Sometimes there remains around the stellate cell a more or less circular space enclosed by what seems to be the inner surface of the original cell-wall, of which the outer portion has blended with the surrounding tissue.

In the account thus given of the development of the spinal cord, I have carefully refrained from indulging in any theoretical views, and have confined myself solely to a faithful description of what was actually seen. A few remarks, however, are required in further explanation of some of the observed facts, and in reference to the conclusions that may be drawn from them.

We have seen that in its earliest stage of development, the spinal cord consists of a canal surrounded only by one uniform or homogeneous layer of small cells or nuclei, which are not distinguishable from each other in appearance, and are so closely aggregated as to seem in actual contact. To call this single layer the epithelium of the cord, appears to me about as incorrect as it would be to call the germinal membrane of the ovum the mucous or internal of the two layers into which it immediately separates; for in the second stage of its development, we find that this single and homogeneous layer constituting the entire substance of the cord, while it continues to increase in depth,

* The connexion of nerve-cells with each other by means of prolongations of their sheaths is well seen in many of the Invertebrata. Fig. 33 shows such a connexion between five cells, from one of the groups of ganglia composing the subœsophageal mass of the common Slug. The central space between these cells is occupied by portions of nerve-fibres running in different directions, as well as by connective tissue continuous with prolongations of the cell-sheaths. It is not, however, denied that some of the processes contain prolongations from the *interior* of the cells. These cells differ considerably both in size and shape. Many of them are enormous. In fig. 33, Plate XLVIII. they are magnified only 420 diameters, and in some parts of the ganglion they reach the prodigious size represented in fig. 34 under the same magnifying-power. The nuclei within the cells are also of extraordinary dimensions, and filled with exceedingly coarse granules, amongst which are a variable number of round nucleoli enclosing some finer granules. Between the larger cells are others of a much smaller but variable size, many of them not exceeding one-fourth the diameter of the *nuclei* of those represented in fig. 33. A great number of the cells are pyriform, and lie side by side in regular rows. The cephalic or supraœsophageal ganglion has an entirely different structure. It consists of two lobes, united above the œsophagus by a thick transverse band or commissure. The portion of each lobe on the side of the median line is a globular and finely granular mass, traversed by a multitude of exceedingly fine fibres proceeding from a somewhat hemispherical layer of small and closely aggregated cells, which partially encloses the inner mass, and forms the lateral crust of the ganglion.

undergoes a differentiation into two distinct layers—an inner, constituting the true epithelium, and an outer, constituting the grey substance; and although the former does not undergo the histological and morphological changes which subsequently take place in the mucous layer of the germinal membrane, yet it is probable that *after* the production of the outer or grey substance, it differs in its histological character from the originally homogeneous layer. This differentiation of structure proceeds very gradually, and is not at first marked by any decided line of separation, or by any difference in the appearance of the structural elements. At the same time there is gradually formed around, and apparently secreted from, the small cells or nuclei, a granular substance that forms into processes or fibres, and constitutes a continuous network by which all the nuclei or cells of both layers are uninterruptedly connected. In the grey substance itself there is at first little or no apparent difference in structure between its anterior and posterior portions, although in each portion darker and more-closely aggregated groups of nuclei may be observed in connexion with the roots of the nerves. But as development progresses, a diversity of structure ensues; for while the nuclei of the *posterior* grey substance, although rather more granular than at first, have scarcely advanced in size, those of the *anterior* substance have increased to double their original diameter, and are connected by thicker fibres, which form a coarser and more granular network. At the same time, around the separate groups of the latter substance, the granular network (seen in fig. 35, Plate XLVIII.) between the nuclei assumes a more sponge-like structure, as represented at *v*, fig. 12. Meanwhile, within the group, there are formed from the nuclei a number of large, roundish or irregular but adjacent cells, with thick nucleated walls (*x x*, fig. 12). It is quite evident that the nucleated tissue constituting the walls of these cavities and the network around them is in every respect similar in appearance to that which is very commonly assumed by the connective tissue of parts external to the cord, as may be seen, for instance, at *b*, fig. 23, Plate XLVII., which represents a portion of the connective tissue on the outer surface of one of the intervertebral ganglia, with the substance of which, however, it is directly continuous.

It appears, then, that in these early stages of development there are at least two kinds of free nuclei in the grey substance of the cord. The one kind appear to develope the general network of tissue which pervades the entire structure, but proceed no further; whereas each of the other kind, while connected with this network as well as with nerve-fibres, developes a nucleated cell with a nucleated wall which is still connected, and ultimately blended, with the surrounding reticular structure. In the cells of the intervertebral ganglia, although the process appears to be *essentially* the same, there is some difference in the appearance they present in the earlier stages of development. Fig. 23, *a*, Plate XLVII. is a small portion of one of the intervertebral ganglia of a fœtal sheep, 1 inch long. Fig. 35, Plate XLVIII. is a portion of the dark group of nuclei in the anterior grey substance of the cord, destined to be developed into large nerve-cells, from the same fœtus. In the former the nuclei are joined by more sharply defined fibres, and there is an absence of the delicate granular network surrounding

the nuclei in the latter. As development advances, these nuclei or small cells of the intervertebral ganglia simply enlarge, at first, but at the same time are connected with each other and with intervening granular nuclei by fine fibres, as shown in fig. 24, Plate XLVII. At a later period a very distinct and well-defined nucleus, surrounded by a variously shaped granular mass, makes its appearance within each cell; while its surface becomes the cell-wall, which at first is thin, but gradually increases in thickness. Now the surfaces of these cells are in connexion not only with the intervening nucleated fibres (as shown in fig. 24) which are continuous with the connective tissue forming the sheath of the ganglion, but also with the walls of the adjacent blood-vessels, as seen at *c*, *c* in the same figure; and it is probably through the medium of this nucleated tissue that the developing cells are supplied with nutritive fluid. Indeed, if we except the muscular fibre-cells, with which some of them are provided, the walls of the blood-vessels are only a part of the pia mater and connective tissue between them. On examining the layer of pia mater which immediately surrounds the cord, it may be seen to connect the walls of the blood-vessels which it contains with the sheaths of the intervertebral ganglia, and, through this, with the sheaths of their nerve-cells, on one side, and on the other side with the connective tissue or pia mater within the cord itself. In fig. 36, Plate XLVIII., *a a'* represent the outer surface of the cord; *b b* the outer part of one of the intervertebral ganglia; and *c c'* the intervening layer of pia mater, containing blood-vessels, *d*, *e*. On its left side, the walls of the vessels (*e*, *d*), containing some globules, are seen to be connected by a continuous and nucleated network with the sheath of the ganglion, *b b*; and from the right side of the walls a series of processes or fibres enter the cord (particularly at *a*, *a'*), in which they are continuous with the reticular tissue of both its white and grey substance. At *c'* there intervenes, between the transversely-cut vessel (*d*) and the cord, a layer of pia mater, from which similar processes are derived. These processes are not branches of the blood-vessels; and they enter the cord around the whole of its circumference. Now, in the anterior median fissure, it may be seen beyond all question, as already stated, that this layer of pia mater, with the walls of the blood-vessels which it contains, is directly continuous with the processes of the epithelium surrounding the front of the canal (see figs. 4, 8, 9, & 14); and therefore we are warranted in concluding that a similar continuity exists within and around the remaining parts of the cord. But this is only an *à priori* confirmation of what I long ago actually observed and described in the adult cord *. And since the sheaths of the nerve-cells have been shown to be continuous with, and indeed to form a part of, the reticular connective tissue of the cord, which is itself continuous with the pia mater of the surface, it is evident that the processes of the epithelium, the pia mater and connective tissue within the cord, the walls of the blood-vessels, and the sheaths of the nerve-cells must be all uninterruptedly continuous with each other. But the sheaths of the nerve-cells are certainly connected with the surfaces of their granular contents; and in the fully-developed cord, where the cell-

* Philosophical Transactions, 1851 and 1859.

sheaths are much finer and thinner, processes from the cells are continuous by fine subdivisions with the surrounding reticular structure, as shown in fig. 17, Plate XLVII. These observations, then, appear to throw important light on the question which I formerly proposed, as to whether there is any actual and essential difference between the connective and the true nerve-tissue, or "whether the connective tissue of the cord be intermediate in its nature, passing on the one hand into *nerve*-tissue, and on the other into *pia mater*"*. We have seen that the cell-sheath or wall is the product of, and indeed is constituted by, the very surface of the primitive nucleus or cell, and that, while it ever after remains in connexion with its contents, it forms a part of the surrounding connective tissue, which is itself a prolongation not only of the pia mater of the surface, as well as the walls of the blood-vessels, but also of the processes of the epithelium. But although there is this uninterrupted continuity between all the constituent elements of the cord—although, perhaps, the nerve-tissue actually changes by insensible degrees into the tissues with which it is continuous—and although the cell-wall, which forms part of the surrounding reticular structure, is a product of the primitive nucleus, there is yet no ground for believing that the connective tissue, as such, can ever develope itself into nerve-tissue, any more than that any one of the differentiated parts of a fully-developed organ can reproduce the entire structure; for the nerve-cell, although it developes from itself its own sheath, which forms part of the nucleated connective tissue, produces something more than this tissue, viz. the granular contents of the cell†.

We know that processes of the nerve-cells constitute the axis-cylinders of the vaso-motor nerves distributed to parts external to the cord; and therefore it seems probable that the finer processes which are lost by subdivision in the pia mater or connective tissue within the cord are the means of transmitting nerve-power to that tissue and to the coats of its blood-vessels, from which, by their uninterrupted connexion with them, as already shown, the nerve-cells in return receive their supply of nutriment.

* Philosophical Transactions, 1859, Part I. p. 442.

† There can be no doubt that a considerable proportion of the gelatinous substance and other parts of the posterior cornu are of the nature of pia mater; but amongst this there are numerous small nerve-cells. As I have dwelt, however, on this point in another place (Phil. Trans. 1859), I need not repeat my remarks.

Explanation of the Plates.

PLATE XLV.

Fig. 1. A transverse section of the spinal column and cord in the upper part of the lumbar enlargement of a fœtal sheep $\frac{3}{4}$ inch in length, magnified 60 diameters:—*h*, anterior white column; *f*, anterior grey substance; *g*, anterior nerve-roots; *c*, posterior white column; *b b'*, posterior grey substance; *d*, posterior nerve-roots; *e*, intervertebral ganglion; *a*, epithelial layer surrounding the front of the canal; *j j*, body of vertebra; *k*, chorda dorsalis; *i*, connective tissue uniting the body of the vertebra and intervertebral ganglia to the circumference of the cord.

Fig. 2. A portion of the outer surface of the posterior grey substance (*b*) in connexion with the inner surface of the posterior white column (*a*); magnified 420 diameters; from the same fœtus.

Fig. 3. Transverse section of spinal cord in the upper part of the lumbar enlargement, magnified 60 diameters, from a fœtal sheep 1 inch in length:— *h'*, lateral column.

Fig. 4. Transverse section of spinal cord in the upper part of the lumbar enlargement, magnified 60 diameters, from a fœtal sheep 2 inches long:—*h'*, lateral white column; *r*, gelatinous substance; *p*, *p'*, inner portions of posterior white column; *l b*, caput cornu; *n*, posterior median fissure; *q q*, cervix cornu; *w*, *w*, groups of large nerve-cells of anterior cornu; *o*, central canal; *m*, anterior median fissure.

Fig. 5. Transverse section of the spinal cord of the same fœtus, from the middle of the dorsal region.

Fig. 6. A similar section from the upper part of the dorsal region.

Fig. 7. Another, from the middle of the cervical enlargement.

Fig. 9. A portion of the section represented in fig. 8, magnified 420 diameters:—*o*, anterior portion of the canal; *s s*, epithelium surrounding it; *f*, nuclei forming the anterior grey substance; *g*, inner bundle of anterior roots entering the grey substance; *h*, *h*, inner parts of the anterior white columns; *m*, anterior median fissure between them. The epithelium is seen to be continuous on the one hand with the network of fibres between the nuclei of the anterior grey substance (*f*), and on the other hand with the network of pia mater (*m*) prolonged from the circumference of the cord into the anterior median fissure.

Fig. 9+. Fresh nerve-fibres from the sciatic nerve of a human fœtus of four months: on the left is a single fibre; on the right several are seen as they lie together constituting a nerve.

Fig. 10. A portion of the grey substance near the edge of the posterior cornu traversed by fibres of the posterior roots (*d*). From a fœtal sheep $2\frac{1}{4}$ inches long; magnified 670 diameters.

PLATE XLVI.

Fig. 8. A transverse section through the spinal column and cord of a human fœtus of nine weeks, from the cervical enlargement; magnified 50 diameters;—*z*, lamina of vertebra; *z'*, muscular fibres.

Fig. 13. One, and part of the other, lateral half of a transverse section through the lumbar enlargement of the spinal cord of a fœtal sheep 4 inches long:—*l b*, caput cornu posterioris.

Fig. 14. A similar portion of a transverse section through the middle of the lumbar enlargement of a fœtal ox 5 inches long:—*l b*, caput cornu posterioris, consisting of a dark mass of closely aggregated nuclei. From the outer edge of this mass, as well as from that of the rest of the grey substance, nuclei are scattered in smaller numbers through the white columns.

PLATE XLVII.

Fig. 11. Grey substance from the middle of the anterior cornu, traversed by anterior nerve-roots; from a fœtal sheep 2½ inches long; magnified 670 diameters.

Fig. 12. Portion of the anterior grey and white substances of a fœtal sheep 2½ inches long; magnified 420 diameters:—*y y'*, internal part of the anterior white column, bordering the grey substance; *x x*, group of large nerve-cells in process of development; *v*, granular and nucleated network nearer the middle of the anterior cornu.

Fig. 15. Portions of a longitudinal section of the grey substance of the same fœtus, in a direction before-backward; magnified 420 diameters. I. Part of the caput cornu posterioris, intersected by the deep decussating fibres of the posterior roots, and posterior white column. II. Middle portion of the grey substance (between *b* and *f*, fig. 14), in which the nuclei are much larger, and the network between them becomes gradually coarser and looser as it proceeds forward. III. A group of the large nerve-cells of the anterior cornu (*w w*, fig. 14), surrounded by thick walls, with intervening nuclei.

Fig. 16. Portion of a longitudinal section of the middle of the grey substance (corresponding to II, fig. 15), from a fœtal sheep 8 inches long; magnified 420 diameters. Numerous fusiform, triangular, and crescentic cells have become developed in it.

Fig. 17. Stellate nerve-cell from the nucleus cervicis cornu (posterior vesicular column) of a human fœtus of six months; magnified 420 diameters. Some of the processes are seen ramifying and becoming continuous with the surrounding network. It is not often seen so distinctly as in this case.

Fig. 17*. Cells from the posterior grey substance of a human fœtus of four months; ×670.

Fig. 18. A portion of one of the posterior white columns of the spinal cord of a human fœtus of five months, showing the numerous nuclei with which it is interspersed; magnified 670 diameters.

Fig. 19. A transverse section of the spinal column and cord of the chick at the end of the fifth day of incubation; magnified 60 diameters.

Fig. 20. A similar section of the cord at the end of the ninth day of incubation:—*n'*, large mass of nucleated connective tissue replacing the inner portion of the posterior columns.

Fig. 21. A transverse section of the cord of the same, through the lower part of the sacral enlargement.

Fig. 22. A similar section a little higher up, between figs. 20 & 21.

Fig. 23. Part of an intervertebral ganglion and surrounding connective tissue of a fœtal sheep 1 inch long:—*a*, nuclei or small cells of the ganglion; *b*, connective tissue on its outer surface; magnified 420 diameters.

Fig. 24. The same from a fœtal sheep $1\frac{3}{4}$ inch in length. The nerve-cells have enlarged and are connected by a continuous network with each other, with the nerve-fibres, with intervening granular nuclei, as at *b'*, and with nucleated fibres connecting the ganglion with the lamina of the vertebra, at *b*. At *a* indistinct nuclei are seen in the interior of the cells; magnified 420 diameters.

Fig. 24*. Cells from the same at a little later period of fœtal life; × 420.

Fig. 25. Portion of a transverse section of the intervertebral ganglion of a fœtal sheep about 3 inches long. The cells have increased in size, are pyriform, a well-defined nucleus has made its appearance in each, and between the cells the interspaces are occupied by small angular or elongated nuclei.

Fig. 25*. Cells from the intervertebral ganglion of a human fœtus of nine weeks; from one of the ganglia represented at *e*, *e*, fig. 8, Plate XLVI.

Fig. 26. A nerve-fibre dividing into branches to be connected with cells. From the intervertebral ganglion of a sheep 3 inches long; magnified 670 diameters.

Fig. 27. Another fibre connected with cells by division.

Fig. 28. A group of cells in their natural position connected with ramifying nerve-fibres; small nuclei occupy the spaces between them; magnified 420 diameters.

Fig. 29. Portion of such a group, showing the manner in which the nerve-fibres are connected with it.

PLATE XLVIII.

Fig. 30. Isolated nerve-cells from the same.

Fig. 31. Group of cells from the intervertebral ganglion of a fœtal sheep 8 inches long; magnified 420 diameters: each cell is enveloped in a thick nucleated sheath.

Fig. 32. Group of cells, with nerve-fibres, from the anterior part of one of the intervertebral ganglia of the chick at the end of the ninth day of incubation; magni-

fied 420 diameters. At *a* the cells are in an earlier state of development, neither their walls nor their nuclei being yet very distinct.

Fig. 33. Five large and two small cells from one of the group of subœsophageal ganglia of the common slug; magnified 420 diameters.

Fig. 34. An enormous cell from the same; magnified 420 diameters.

Fig. 35. Group of small cells or apparent nuclei, destined to be developed into the large cells of the anterior cornu, from a fœtal sheep 1 inch in length. The cells are surrounded and connected by a delicate granular network.

Fig. 36. Part of the spinal cord, intervertebral ganglion, and intervening pia mater from a fœtal sheep 3 inches long:—*a a'*, outer surface of the cord; *b b*, sheath and outer portion of intervertebral ganglion, with some of the marginal cells; *c c'*, intervening pia mater; *d*, a blood-vessel cut transversely and full of blood-globules; *e*, another blood-vessel, running round the cord: at *a* transverse processes are seen proceeding from the nucleated wall of the vessel to the surface of the cord; at *a'* similar processes are given off from the pia mater, which is merely a continuation of the nucleated walls of the vessels. On the other side, the pia mater and walls of the blood-vessels are seen to be continuous with the nucleated investment of the intervertebral ganglion, *b b*.

Figs. 37 to 44 are exact representations of transverse sections of the spinal cord of a human fœtus, all magnified about 34 diameters. The actual and relative quantities of the grey and white substance are well seen in each.

Fig. 37. A transverse section of the conus medullaris:—*l b*, caput cornu posterioris; *f*, anterior cornu; *o*, canal; *c*, posterior white column; *k'*, lateral white column; *h*, anterior white column; *m*, anterior median fissure; *n*, posterior median fissure.

Fig. 38. A transverse section through the lower third of the lumbar enlargement:—*d*, posterior nerve-roots; *q*, posterior vesicular column; *w*, increasing groups of large nerve-cells in the anterior cornu.

Fig. 39. A similar section through the middle of lumbar enlargement. The posterior vesicular column (*q*) forming the inner half of the cervix cornu has enlarged, but hitherto consists chiefly of a multitude of *small* cells. Through it and on its outer side several curved bundles of the posterior roots sweep forward and inward, and separate it from the outer half of the cervix, at the border of which are several dark spots, representing the cut ends of longitudinal bundles. In front of the canal (*o*) are the decussating fibres of the anterior commissure, and behind it is the posterior commissure. The group of nerve-cells in the anterior cornu has much enlarged.

Fig. 40. Similar section through the upper third of the lumbar enlargement. Here the *cells* of the posterior vesicular column (*q*) or nucleus of the cervix cornu have increased considerably in size: they are nearly all equal to those of the anterior cornu. The groups in the anterior cornu are much diminished.

Fig. 41. Section through the lowest part of the dorsal region, or upper end of the lumbar enlargement. Here the posterior vesicular column (*q*) is larger than in any other part of the cord, and consists chiefly of large, oval and stellate cells. Here also we first distinctly see the *tractus intermedio-lateralis* (*t*), a tract of smaller cells between the anterior and posterior cornua, and projecting in a conical form from the border of the grey substance into the lateral white column.

Fig. 42. Another section, through the *middle* of the dorsal region. The posterior vesicular column diminishes in size.

Fig. 43. A section through the *upper* part of the dorsal region; the tractus intermedio-lateralis (*t*) is very prominent.

Fig. 44. Another, through the middle of the cervical enlargement:—*e'*, the posterior lateral fissure, through which the outer fibres of the posterior roots (*d*) are seen to reach the dark spots or longitudinal bundles on the outer side of the cervix cornu, with which they become continuous. These longitudinal bundles are more numerous here than in any other region of the cord. On the inner side of the cornu, other fibres of the roots are seen sweeping both around and within the posterior vesicular column (*q*). This column is here again large, but consists chiefly of a multitude of *small* nerve-cells. The groups of nerve-cells in the anterior cornu have again increased in size. These groups, and indeed the whole of the anterior cornu, as well as the outer part of the cervix of the posterior cornu, are supplied, as represented, on the left side, by a beautiful branch of a large blood-vessel (*v*), which enters through the anterior median fissure (*m*), and bifurcates right and left, at its bottom, through the anterior commissure. The parts behind the canal are supplied by other vessels running transversely and derived in part from a larger longitudinal vessel on each side of the canal, and of which the cut ends are seen in the figure. In the lateral white column is a somewhat oval space (*g'*) occupying nearly the whole of its area, and of a lighter and greyer colour than the rest. This is apparently due to a greater abundance of blood-vessels and pia mater. It is limited chiefly to the cervical and dorsal region. The wedge-shaped column (*p'*) on each side of the posterior median fissure, and forming part of the posterior white column, is very strongly marked in this figure. Its tapering end is gradually lost in the deep part of the column on its outer side. At this period they are limited almost entirely to the cervical enlargement; at an earlier period they may be traced lower down (see figs. 4, 5, 6, & 7).

Fig. 45. Part of the chorda dorsalis of the chick at the end of the ninth day of incubation, with some of the surrounding cartilage-cells:—*a*, chorda dorsalis, consisting of a nucleated network of fibres, having precisely the appearance of connective tissue; *b*, cartilage-cells around its circumference, in different stages of development: in one the nucleus is seen undergoing division.

XXXVII. *On Spectra of Electric Light, as modified by the Nature of the Electrodes and the Media of Discharge.* *By the Rev.* T. R. Robinson, *D.D., F.R.S., &c.*

Received June 19*,—Read June 19, 1862.

The important discovery of Wheatstone, that the spectra of electric sparks contain brilliant lines whose character depends on the nature of the electrodes, after being almost neglected for several years, has lately become an object of great interest; and much additional light has been thrown on it by several physicists, of whom Masson, Ångström, Plücker, and Kirchhoff are the most conspicuous. Ångström has announced as a general law that the lines in question are produced by the electric current igniting the medium in which the discharge takes place, or molecules of the electrodes which are torn off by its passage, that each of these actions produces its own spectrum, and that those spectra are simply superposed without any modification. The gases with which he worked were at the ordinary pressure. Plücker, on the other hand, used the well-known Geissler tubes, which contain minute proportions of highly rarefied gas or vapour. He attaches very little importance to the lines due to the electrodes (*metallic* lines), which he thinks are confined to those portions of the spark near the electrodes; and he maintains that in the centre of an exhausted tube of some length only gaseous lines are seen. He was embarrassed in several instances by the decomposition or absorption of the gaseous media; and there must always be some doubt as to the precise nature of these media, as the tubes are hermetically sealed. On the other hand, Kirchhoff seems to attach most importance to the metallic lines, whose influence he has exhibited to a wonderful extent by a spectrum-apparatus probably unrivalled. All hold the doctrine of an essential connexion between the character of the spectral lines and the chemical nature of the substances which are present in the track of the discharge; and the last, in conjunction with Bunsen, has based on this principle the new system of spectral analysis, which is rapidly becoming popular, and has applied it to explain the dark lines of the solar spectrum in a way which, if not absolutely certain, is singularly elegant. Yet it is impossible to overlook the fact that, in all this, much is assumed, not proved. Has it been established that these lines depend so absolutely on chemical character that none of them can be common to two or more different bodies? Has it been ascertained that, while *the chemical nature* of the bodies present remains unchanged, the lines never vary if the circumstances of mass, density, &c. are changed? And what evidence have we that spectra are superposed, so that we observe the full sum of the spectra which the

* The continuation of the paper, from p. 974 to the end, was not received complete till September 1; but the conclusions therein contained are embodied in the abstract presented to the Society on June 19, 1862.

electrodes and medium would produce separately? Lastly, is it certain that electricity produces light merely by its heating power? and may not the same action which produces thermic vibrations, also (and independently) produce luminous?

Some of these questions I have endeavoured; to investigate and the attempt can scarcely fail to be of use, were it only to direct attention to the subject.

My attention was originally turned to it by observing, some years ago, that the discharge in carbonic oxide, which is white at common pressures, becomes bright green when the gas is highly rarefied. The spectra in these cases differed so much that I determined to examine them in various gases and metals; and I procured the apparatus which seemed necessary. That of STEINHEIL had not been contrived then; and my want of experience in such researches caused at first some mistakes, but by degrees I corrected them; and though my instrument is of comparatively limited power, the results are, I hope, not without importance; and I have given details sufficient to estimate the errors which may affect them.

The source of electricity in my experiments was an induction-machine. Till July 1860 I used one by HEARDER, having three miles of secondary wire; after that, one which I have described*, with the substitution of copper wire for iron. It has 9·5 miles, of which three are not lapped, merely varnished; and when excited by three Grove's, each of which has 49 square inches of platinum acting, it gives abundantly sparks 6·8 inches long. By a simple device its two coils can be in an instant made to act collaterally instead of consecutively, thus reducing the intensity but doubling the quantity. Then the sparks are only 2·5 inches, but very dense and luminous, and possessing a far higher power of ignition. A Leyden jar, each coating 1·25 foot, was normally connected with the terminals, as the spectrum of the simple spark is far more faint and unsteady: I have given one as a specimen in Table III. With this jar there is a continuous stream of discharge at 0·6 inch.

The discharges were made in the open air, or in tubes about 0·2 inch diameter and 6 inches long. With rarefied gases they would be more luminous if the tubes were capillary; but in that case it would be very difficult to clean them from the coatings of metal or oxide which are deposited, most densely near the negative electrode, but often on the whole interval. In some metals, of which the most notable are lead, cadmium, bismuth, antimony, arsenic, and above all tellurium, this deposit was so thick that at the close of an experiment it was difficult to see the fainter lines, and I found it necessary to employ for common density a tube 1 inch diameter. Even this was coated, but not so thickly as to give much trouble. The upper electrode (which was, in all cases but one, positive) was attached to platinum wire fused in the tube. It was sometimes soldered to it, at other times twisted with it; and when I could not procure the metal as wire or foil, a globule of it was fused by a gas-blowpipe, a platinum wire inserted in this, and the heat withdrawn. For nickel and cobalt, the blowpipe was oxyhydrogen. As the electric light does not spread over the positive electrode, it was unnecessary to insulate the platinum wire; but with the negative it is otherwise; and when I had not enough of

* Philosophical Magazine, April 1859.

the body to give a length of some inches, it was inserted in a piece of quill tube, whose lower extremity was fused on platinum wire reaching up to it; and this was inserted in the discharge-tube. In tubes the distance of the electrodes was about 0·75, in open air 0·10. The discharge-tube was cemented in a cap screwed to the air-pump, or rather to a transfer piece. This is a cylinder of brass with a concave screw above, a stopcock below screwing to the air-pump, and a lateral one connected with a desiccator. The desiccator is a bottle 8 inches deep and 2 inches diameter, fitted with a ground stopper, in which are two apertures. In one of these is cemented a tube which is connected with the transfer; in the other, one descending to the bottom of the bottle, where it is drawn into a capillary point, its upper end being connected with either another desiccator or a gasometer. The desiccator is filled nearly with sulphuric acid. Supposing the transfer and the tube exhausted, shut off the air-pump cock and cautiously open that which connects the desiccator; gas bubbles up slowly through the acid and fills the transfer and tube. Shut off the desiccator, connect the pump, and exhaust. By repeating this process *ad libitum* all traces of air or any gas previously used are removed, and nothing is present but the subject of experiment. It is almost needless to say that every part of this apparatus, including the air-pump, must be *absolutely** air-tight. To ascertain whether this means of desiccation is sufficient, I used Kater's oat-beard hygrometer. In the air of the room it read at 60° 3·358 R. It was then placed under a receiver containing a capsule exposing 20 square inches of sulphuric acid for five hours at a pressure of 0·3 inch, when it read 0·455 R. The receiver was then filled with air drawn through the desiccator as rapidly as could be done without drawing acid into the pump. In 10^m it read 0·285 R. Admitting air and introducing a slip of bibulous paper moistened with water, in 40^m it was 8·480 R; and when left in the air of the room some hours it was again 3·258. It is therefore evident that in this respect nothing more can be desired. Sulphuric acid also absorbs sulphurous acid and nitric oxide; but when other acids might be present, a second desiccator was used filled with concentrated solution of potassa.

The gasometer was made of a Woulfe's bottle holding 75 cubic inches. In its central neck is cemented a siphon, one branch of which reaches to its bottom, the other to the bottom of a bottle of rather larger capacity; in the other two necks, stopcocks are cemented, one of which (A) is connected by elastic tube with the desiccator, the other (B) with any apparatus for generating gas. Suppose the Woulfe filled with water (or on a smaller scale with mercury). Let gas be supplied to B, the water will be displaced by it through the siphon into the bottle; then closing B and opening A, the transfer and its tube are filled. If the water has been boiled for a few hours and cooled without exposure to the air, I find that gas continues in this gasometer sensibly pure for a much longer period than the duration of a day's observations. For operating on vapours free from any mixture of permanent gas, I use a mercurial apparatus, consisting of a strong Woulfe's bottle in whose three necks are ground (1) a glass stopcock, (2) a tube in which

* That which I use has kept for a month a vacuum of 0·1 inch without variation of 0·01.

a platinum wire is sealed long enough to dip in the mercury and serve as the negative electrode, (3) a tube also dipping in the mercury, and with a platinum electrode at top. If the bottle be filled one-third with pure mercury, and the stopcock be connected by a caoutchouc tube* with the transfer and the apparatus exhausted, the tube can be filled with mercury, which on erecting it falls, leaving a vacuum, through which discharges can be passed by the electrodes. If the tube has been *perfectly* cleaned by filling it with nitric acid and washing it with distilled water, dried by sulphuric acid in a vacuum, and finally wiped with a morsel of linen which has been boiled in distilled water, after being fastened to a flexible wire, on inclining the tube the mercury will fill it without leaving the least speck of air, and will often adhere with considerable force. It, however, always falls at the first discharge. In this case the space is filled with mercurial vapour alone. If a few drops of any volatile fluid be introduced into the tube, by filling it with mercury the excess is expelled, and the vacuum contains only its vapour highly rarefied. With phosphorus, the tube filled with water was warmed till it fused and adhered to the upper part; the water was removed, and the tube put in its place. The apparatus was then repeatedly filled with dry nitrogen till all traces of moisture disappeared. If a platinum wire of sufficient length be introduced below, both electrodes are platinum; and if the upper part be bent so that the descending branch remains full of mercury, both are of that metal.

Prisms.—For three-fourths of the observations I used a prism by Merz, with an angle 45° 35′·4. By sets of from eight to twelve it gives, for the deviations of Fraunhofer's lines,

A . . .	32° 20′·00	. . . μ	1·6230
B . . .	32 32·04	. . . .	1·6259
C . . .	32 38·88	. . . .	1·6285
D . . .	32 56·50	. . . .	1·6336
E . . .	33 20·26	. . . .	1·6405
F . . .	33 41·67	. . . .	1·6467
G . . .	34 23·06	. . . .	1·6587
H . . .	35 0·06	. . . .	1·6692

It is therefore nearly identical with Fraunhofer's flint No. 2, but in dispersive power it is far inferior to those used by Masson and Plücker. After working with it a long time, I found that several bright but cloudy bands which it showed were resolved into two, three, or more by a prism of bisulphuret of carbon having an angle of 60°. The indices of this fluid change so much with temperature, that I did not venture to employ it; and I obtained from Mr. Dubosco a prism of 60° 3′·54 angle, which, though nearly of the same density as the Merz, is more effective, in the proportion of 3 to 2. Determining with it Fraunhofer's lines, and comparing with their deviations in Merz, I

* This, with which I was supplied by Messrs. Silver, is far superior to vulcanized tube, which always leaks. The glass apparatus was made with great precision and intelligence by Mr. Casella.

formed by interpolation a Table of reduction to the latter, by means of which all are given on the same scale. The two glasses are so nearly similar, that it was not necessary to go beyond second differences. Even this prism leaves several bands unresolved, though often giving a suspicion of their compound character, which in some recent instances I have verified by combining *two* 60°-prisms of the bisulphuret.

It is an object of great interest to ascertain whether there be any special relations between the wave-lengths of these luminous bands. In aid of this I subjoin a Table giving the value of λ for every five minutes of Merz's deviations within the range of my observations. It has been computed by a very simple form of interpolation given by Professor Stokes*. Assuming $\mu = A + \frac{B}{\lambda^2}$, and taking μ and $\frac{1}{\lambda^2}$ for any two of Fraunhofer's lines, we get, for any intermediate μ, the $\frac{1}{\lambda^2}$ *simply by proportional parts*. This is so accurate, that it gives correctly one of the intermediate lines by taking the double interval, as D from C and E; even H from F and G.

ϕ.	λ.	$\Delta\lambda$.	$\Delta^2\lambda$.	ϕ.	λ.	$\Delta\lambda$.	$\Delta^2\lambda$.	ϕ.	λ.	$\Delta\lambda$.	$\Delta^2\lambda$.
° ′				° ′				° ′			
32 35	2493			33 25	1909		+ 2	34 15	1620		+ 1
40	2405	−88	+ 9	30	1872	−37	+ 2	20	1599	−21	+ 2
45	2326	−79	+10	35	1837	−35	+ 3	25	1580	−19	+ 1
50	2257	−69	+ 6	40	1805	−32	+ 1	30	1562	−18	+ 0
55	2194	−63	+ 5	45	1774	−31	+ 2	35	1544	−18	+ 0
33 0	2136	−58	+ 5	50	1745	−29	+ 2	40	1526	−18	+ 1
5	2083	−53	+ 4	55	1718	−27	+ 1	45	1509	−17	+ 1
10	2034	−49	+ 4	34 0	1692	−26	+ 1	50	1493	−16	+ 1
15	1989	−45	+ 4	5	1667	−25	+ 1	55	1478	−15	+ 1
20	1948	−41	+ 2	10	1643	−24	+ 1	35 0	1464	−14	
25	1909	−39	+ 2	15	1620	−23	+ 1				

Theodolite.—For the use of this instrument I am indebted to Mr. Grubb, who made it many years since to determine the μs of the glasses for his object-glasses. It is of simple and very firm construction. A strong brass disk, supported by three screws, has on its upper surface a circle 9·5 inches diameter graduated to half degrees, and carries laterally the supports of a collimating telescope 9·5 inches focus and 1 inch aperture, which is provided with an adjustable slit. Above the disk turns a brass plate bearing two verniers in the plane of the divisions (which read to minutes), and supporting the telescope, with a triple object-glass 7 inches focus and 0·9 inch aperture. Below the disk turns another circle, similarly divided on its cylindric surface; its axis rises through that of the upper plate, and carries a table 3 inches diameter, which bears the prism. The axis of the prism is adjusted by observing the images of the slit reflected from its surfaces, which also give its angle by means of the lower circle. Some of these matters require a few remarks.

1. The telescope (and the collimator also), though sensibly achromatic on a day-object

* Report of the British Association, 1849, Trans. of Sections, p. 11.

or the moon (and very sharp), is over-corrected for G and the rays beyond it: as no provision was made for changing the distance of its object-glass from the system of wires, I at first had some difficulty from parallax at that end of the spectrum, till such an adjustment was applied. The eyepiece (positive, magnifying nine times) was also not achromatic, and had to be constantly focused. It was replaced by a microscope's objective about 0·4 inch focus, magnifying 14 with the prism. A higher power, and even a larger object-glass, avails little in comparison of an increase of the prism's dispersion. Thirdly, I found the cross of spider's lines useless, except for the brightest lines. In the spectra of rarefied gases, which are very faint, it is difficult to see them, and I substituted the point of a fine needle, carefully ground to be a sharp wedge. One can estimate very nicely the equality of the tongues of light on each side. These changes were not made till about fifty spectra had been measured, which, therefore, are not as well determined as the rest.

2. The collimator certainly possesses advantages over the simple slit which FRAUNHOFER and his predecessors used in studying the spectrum. It requires no correction for parallax, secures from any accidental shift of the theodolite, and brings the observer close to his work; but it has the great defect of diminishing the light. Unless the slit be very narrow, it is impossible to distinguish close and fine lines. I find that with the instrument which I am describing, and the Merz prism, I cannot see D double if the slit subtend more than 72″, which corresponds to a width of $\frac{1}{350}$ inch. If it be 3′ (the opening used by PLÜCKER) I cannot see any of FRAUNHOFER's lines, and the finer parts of electric spectra are lost. Obviously the quantity of light must diminish with the slit, and the evil is made greater by the necessity of keeping the latter at some distance from the discharge. If it be nearer than 1·5 inch, or at most 1 inch, the inductive action of the spark *charges* the theodolite, and the observer, on applying his eye to the telescope, gets a stream of pungent sparks anything but pleasant. But in order that the whole object-glass may be illuminated, we must have this distance less than $\frac{f^2}{\text{A cosecant } 72'' - f}$ A and f being the aperture and focus. This limit in the present instance $=0{\cdot}03$ inch, from which it is obvious that a comparatively small portion of the light can reach the object-glass. I was led to this discussion by a fact which at first startled me a little. When obtaining the deviations of FRAUNHOFER's lines, I was surprised to find that H was not visible to me, nor any line beyond h; though in 1838, with the same prism, but with a slit in the shutter 15 feet distant, I saw several beyond K. I concluded that my eyes had become insensible to rays of short wave-length (in analogy to WOLLASTON's inaudible sounds), or that their humours had undergone some change by which they absorbed that part of the spectrum; but never suspected the collimator. However, last year, while examining a very fine Munich grating belonging to Mr. STOKES, I was surprised to find that it showed me the missing lines perfectly: here the aperture was a slit $\frac{1}{10}$ at 18 feet. He was so kind as to entrust me with the grating; and on my return home I found that with the collimator it behaved no better than the prisms had done, but that with

the plain slit it recovered its power: the same was the case with my prisms. That the sole cause of this was the narrowness of the slit, and not any peculiar action of the collimator, I verified by attaching to the stand of the theodolite a good object-glass of 8 feet focus, and placing it at that distance from the slit ($\frac{1}{96}$). This arrangement gave vision that was first-rate, and showed lines in an electric spectrum 14′ beyond the last of those that were visible in the usual mode of observing. It follows from these facts, that the collimator's focus should be as long as possible consistent with convenience; and I will suggest that it should be a cassegrain instead of an achromatic. The *equivalent* focus of this is from six to seven times that of the large mirror, and I find by a rough trial that the image is very sharp. If the mirrors of A were glass silvered on FOUCAULT'S plan, it would have as much light as the achromatic, and be free from all chromatic error. I have recently found that the brightness of faint lines is much improved by using a cylindric lens before the slit. The slit was generally one minute wide.

3. The precision of the angles measured depends, on the determination of the index-correction, on the precision of the bisection, and on the reading of the circle. The zero was obtained at the beginning, and also often at the end of each set, by bisecting the slit when illuminated by nearly homogeneous light. At first this was done by interposing a slip of red glass; latterly, in preference, by using the flame of a Bunsen burner in which chloride of sodium was present. The bisection is sometimes doubtful from the flicker of the discharges, more frequently from faintness of the lines, whether intrinsic or relative to the ground on which they are seen, and occasionally from want of sufficient light to see the point. The verniers read only to minutes; but the half minute is easily estimated, and so 0′·25 may be considered the uncertainty of reading. It is desirable to form some estimate of the probable amount of error due to the combined action of the three. This is done by observing twice over the same spectra, and comparing the differences of the observed lines; from which may be obtained the probable error, and the probabilities of given observed differences being errors of observation, or evidences of the lines not being identical. Unless the graduation were much finer than it is, this process would not be of any real value; and a much simpler one may serve. In this work 325 such differences were observed, of which number there were,

			Comp.
Equal to 0′	86	 86	. . 239
From 0′ to ±0′·5	131	Not exceeding 0′·5 . .	217 . . 108
From ±0′·5 to ±1′·0 . .	89	Not exceeding 1′·0 . .	306 . . 19
From ±1′·0 to ±1′·5 . .	15	Not above 1′·5 . . .	321 . . 4
Above 1′·5	4		

We may reason thus: if the difference of the places of a certain line in two spectra exceed 0′·5, either the lines are identical and the difference is error, or they are distinct; the probability of the first happening $=\frac{108}{325}$, and therefore that of the other $=\frac{217}{325}$, or it is 2 to 1 they are not the same. If the difference exceed 1′·0, it is 16 to 1, if 1′·5, 80

to 1. Two things, however, must be remembered: these errors may be $\pm$; and therefore, in comparing a series, the limit is nearly doubled; and further, these probabilities may be much modified by other circumstances. For instance, a line or band may be identified by some peculiarity, even if the difference be greater than the probable limit. In general I would fix the limit to $\pm 1'{\cdot}0$ from the mean.

I at first read both verniers; but found this consumed so much time, that I determined the excentricity of the upper circle and allowed for it. This correction for the vernier A $= 0'{\cdot}75 \times \sin(160° + \phi)$.

The gases which I selected for experiment are—1, air; 2, nitrogen obtained by heating nitrite of potassa with saturated solution of sal-ammoniac; 3, oxygen; 4, hydrogen: these last two were obtained by electrolysis of *pure* oil of vitriol diluted with eight volumes of distilled water, in a voltameter of peculiar construction. A porous cell has a cover cemented on it with three tubulures; one for admitting the dilute acid; one for a strong platinum wire to which is soldered with gold a platinum sheet, exposing 19 square inches; the third carries away the evolved gas. Round this cell a larger platinum is rolled, and it is immersed in a jar filled with the same dilute acid. When connected with the three Grove's already mentioned, it gives 8 inches of hydrogen per minute. Both the gases I believe to be quite pure, except as to ozone, when thus obtained. 5. The carbonic oxide was got by heating sulphuric acid with ferrocyanide of potassium.

As to the metals, the platinum and silver were obtained from Messrs. Johnson and Matthey, the aluminium from Paris. I am indebted to the kindness of Dr. Matthiessen for calcium, tellurium, and gold. The palladium was given to me by Dr. Wollaston; tin, lead, and bismuth reduced from oxides carefully prepared; zinc, iron, and antimony, deposited by electrolysis on platinum wires. Cadmium, nickel, cobalt, magnesium, sodium, and potassium were got from Messrs. Jackson and Townson.

The spectra at common pressure (C.P.) are in general magnificent objects. Their ground seems to be a continuous spectrum, of which, however, the brightness varies very much with different substances and at different parts. Sometimes, especially at the violet end, this ground is so faint that its presence might be questioned; but I believe it exists even there. On this are, as it were, superposed luminous lines of every degree of brightness, from a splendour almost insupportable, to a faintness such that (at least with my optical means) the least glimmer of diffused light in the telescope totally effaces them. Most of these lines are (as might be expected) as broad as the image of the slit: a few are much broader, even to six or seven times. Such are, I think, always cloudy and ill defined, giving the impression that they are groups of finer lines, which the optical power is insufficient to separate. In several instances this is shown to be the fact by the combination of two fluid prisms of 60° (2BS.C), of which the two most remarkable are those which I call ζ, in the green, and $\varkappa''$, at the beginning of the violet. The first was seen in the Merz prism as a broad bright band, but it is a crowd of very fine lines, of which the central one is much the brightest; and some of the others are

developed in different spectra: the second (not resolved in Duboscq) consists of six bright and sharp lines. Even this power fails to decompose the remarkable blue-green and violet bands which characterize the hydrogen spectra C.P. Perhaps a third prism might, but there is no room for it on the theodolite.

A third class of lines is narrower than the slit, down to the finest hairbreadth; they are mostly sharp and well defined, sometimes very bright. Their occurrence is not easily explained; for in the ordinary conditions of these observations each ray illuminates the whole slit, and the image of the line due to it ought to be as broad as that slit. The only explanation which has yet been proposed (by PLÜCKER) is that they are caused by the overlapping of two images the distance of whose centres is less than the slit. It is, however, liable to two objections—that the brightness of such an overlap cannot exceed twice that of the ground on which it is seen, and that it would be often resolved by a prism of higher dispersion: the combination 2BS.C disperses seven times as much as the Merz, and ought surely to break up some of them. This is not, as far as I have examined, the case; and some of these lines are as intense as any in the spectrum. These narrow lines are sometimes very thickly crowded, as in the green and blue of iron spectra, and in those of carbonic oxide; and possibly they may compose the bright ground when so close as to be unresolvable. There is a seeming tendency in them to be grouped in two, three, or higher numbers, which, however, might disappear with more powerful prisms; but with those I use one can scarcely avoid thinking that there is some special connexion between the components of such groups; such are enclosed in brackets.

Some of the most brilliant are double, as the orange one γ, supposed to correspond with D (though its components seem to me more separated than those of that line), the splendid yellow δ, and the greens η and θ.

At that boundary of the spectrum which corresponds to the negative electrode (and in a much less degree at the positive) extremely intense lines are seen, especially in the green, which however are short: bismuth, zinc, lead, and arsenic are the best examples of this. These are generally supposed to be metallic lines, and to proceed from the intense dispersion of metal near the electrodes, especially the negative. It has even been proposed to consider this not crossing the entire breadth of the spectrum as a test of metallic origin, and to regard the others as gaseous. I, however, find that these very lines can be traced entirely across though sometimes very faint, except when the entire part is covered with a sort of bright haze, through or on which nothing can be seen which is not very bright. It seems to me that the existence of a line and its brightness depend on different causes; and I shall give instances when the *same* line assumes very different aspects as the media of discharge are changed. I may add that the sort of haze just mentioned does not occur at the negative electrode.

The spark discharge without a jar is so much fainter that none but the brightest lines can be seen. If the surface of the jar be increased (for the converse reason) more lines are visible, but I think no new ones are produced. One or two examples will be given,

If the secondary coils be arranged for quantity, the red end is not changed, the violet is much brighter.

On rarefying the gas in which the discharges are made (R) there is at first no change, except perhaps a little diminution of brightness, till at a certain pressure (varying with the media and diameter of the tube) the spectrum fades away. Sometimes, as with CuO (*i. e.* copper electrodes in oxygen), *all vanishes* except a trace of the lines at 0·75 inch; in SbN all but a trace of δ; in NiN, at 2·8 inches, all but a suspicion of violet light, and sometimes perfectly dark bands take the place of bright lines. In others the change is not so striking. In Al, Air, at 1·2 inch, the chief violet lines remain tolerably conspicuous; δ can be seen, but η and κ vanish: in Pt, Air, tube 1 inch diameter, at 6 inches the first half fades to a neutral-tinted haze with faint alternations of brightness, and the rest has eleven definite but faint bands. In general, however, it may be considered the rule that from 3 inches to 1 inch these spectra almost vanish. I will only mention another, PbH. In hydrogen spectra, at C.P. the most distinctive characters are a *very* bright red line (found in all spectra, but not so bright); a very bright and broad one at the confines of green and blue, and a similar one in the violet. Of these the last disappears at 5·3 inches; the red at 3·1 inches; the blue not totally till 0·15 inch; but this is doubtful, as it may have been confounded when waning with another which was near its place. It deserves notice that this disappearance of the peculiar hydrogen bands is also produced when the hydrogen is diluted with air. The electrodes were cobalt; 20 cubic inches of hydrogen were mixed with 10 of air, and the spectrum of the mixture examined; its volume was reduced to 20, 10 more of air added, and so on; the degree of dilution was easily found from the number of additions; and it was found that the violet band vanished when H is 0·2 of the mixture, the blue when 0·09. These correspond to hydrogen under the pressures 6 inches and 2·7 inches: the red could not be determined, as air has the same band.

If in any case we rarefy beyond the limits of these *transition* spectra, bright lines reappear, but not all in the same places or with the same characters. Ordinarily the brilliant lines of the C.P. spectra are wanting, though sometimes lines which are faint in them assume this type in the others. The red, yellow, and green seem diffused in cloudy light; and the violet system is replaced by a set of broad cloudy bands nearly equidistant, and more conspicuous than the less refrangible ones. The red band, which almost always begins the C.P. spectra, is often wanting, and when it does occur is insulated in darkness, but at the other end both spectra are nearly of the same length. These R spectra are in general much less luminous, and show little distinction of colours unless the metal of the electrodes be easily vaporized. That of tellurium is very bright, containing thirteen brilliant lines; and under *every* circumstance of pressure or discharge, those of potassium and sodium show the dazzling orange bands.

As might be expected from their greater faintness, they contain fewer lines, or at least fewer are visible; but it is remarkable that of this number a considerable proportion *is not found* in the C.P. spectra. The percentage deduced from fifteen metals is

Air	0·39
Nitrogen	0·32
Oxygen	0·39
Hydrogen	0·66
Carbonic oxide	0·37

Of this, two explanations may be given. It may be said that these lines are not seen at C.P. because they are overpowered by the brightness of the ground on which they are seen. In some cases (of which examples are given hereafter), especially in hydrogen, this cause does act in some degree. In that gas the centre of the C.P. spectrum was at first observed, where, as I have stated, the finer lines are not easily seen with some metals; and then the percentage was very high; but at the negative boundary this bright haze does not interfere, and when observed *there*, the proportion is almost exactly that of the other gases. Besides, it occurs frequently that in the C.P. spectrum, on each side of the place where the missing line should be, faint and narrow lines are seen with perfect distinctness. The other solution is this, that these lines do not depend entirely on the chemical character of the media and electrodes, but also on their molecular condition. On any other supposition it seems hard to conceive the passage from the C.P. to the transition spectrum, and the increase of brightness from that to the R one, the same chemical elements being present in the three.

In presenting the measures of these spectra, there is a difficulty arising from the impossibility of giving, within any practicable limits, the distinctive characters of the phenomena, though they are of considerable importance. For instance, the orange band γ, which in the sodium spectrum is "intensely bright," is in Pt, CO "faint, scarcely visible." To tabulate them I must restrict myself to a few distinctive symbols. First, the lines which are far transcendent in brilliancy, and are not less broad than the image of the slit, I denote by a $*$. This implies merely that they surpass the others greatly; one in red or violet may fully deserve this symbol, though it would seem dull beside δ or θ. Not very frequently the same line has this mark in C.P. and R, but, except with sodium and potassium, less bright; and sometimes one which is faint in C.P. is a $*$ in R. Then follow

Very bright, bright	vb, b
Conspicuous (from surrounding faintness rather than intense brightness)	c
Faint, very faint	f, vf
Narrower than slit	n
Very narrow, like a hair	vn
Wider than slit (the exponent expressing how many times as wide)	w^n
When they are on an obscure ground	o

The symbol R implies that the pressure $=0{\cdot}2$ inch unless a different one is stated.

I shall commence with aluminium, which I selected as the type because, from its small dispersion at the negative electrode, it may be assumed that its influence on the spectrum bears a small proportion to that of the gas.

TABLE I.—Aluminium.

		Air.		Nitrogen.		Oxygen.		Hydrogen.		Carb. oxide.	
		C.P.	R.	C.P.	R.	C.P.	R.	C.P.	R.	C.P.	R.
1.	32 α	26 *	.....	39 *	39·5 vf.	.....	.....	38·7 * c.	.....	38·8 f.	.....
2.	α′	40·7 c.	.....	40·5 nc.	.....	40·9 *	.....	.....	.....	.....	.....
3.		43·6 f.	.....	.....	.....	43·4 c.	.....	43·6 f.	42·8 * c.	.....	.....
4.	β	46·8 f.	.....	46 nf.	.....	47·4 f.	.....	45·5 f.	.....	48 f.	.....
5.	β′	48·8 *	.....	48·5 *	.....	49·4 *	.....	.....	.....	49·8 f.	.....
6.		.....	51·5 f.	.....	52 f.	.....	.....	.....	51·3 f.	.....	52 f.
7.	γ	55 *	56·5 vf.	55 *	.....	56·4 b.	54 f.	.....	.....	55·5 b.	.....
8.	32	57·7 vf.	.....	.....	.....	.....	.....	57·7 f.	.....	.....	.....
9.	33	0·3 vf.	1·3 vf.	.....	59·5 nf.	.....	1·5 f.	59·5 f.	59·3	1·7	.....
10.		2·6 c.	.....	2·5 nb.	.....	.....	.....	3 f.	.....	.....	2·5 f.
11.	ζ	4 *	.....	3 *	.....	3·4 vn.	.....	3·3 b.	.....	3·2 *	.....
12.		.....	.....	.....	.....	5·4 bn.	.....	6 c.	6·8 f.	5·5 f.	6
13.		7·3 f.	7·5 wb.	.....	7 wf.	7·9 vn.	7·5 b.	8 c.	.....	then 4 vn.	.....
14.		9·4 vb.	.....	8·5 b.	.....	.....	.....	.....	.....	.....	.....
15.	ε′	11 b.	.....	10 b.	.....	10·4 f.	11 f.	10·4	.....	.....	.....
		11·4 nf.									
16.	ε″	12 b	12·3 bn.	12 c.	13 nb.	13·4 b.	.....	12·7 f.	.....	12 f.	13·5 f.
17.		14 f.	.....	.....	.....	.....	15	.....	.....	then 3 vn.	.....
18.	ζ	16 nb. 18 nb.	17 vf.	17·5 w².	16·5 wf.	17·4 b.	18 b.	18 f.	.....	18 f. two.	.....
19.		20 vf.	.....	20 f.	20 f.	.....	.....	19·7 f.	.....	21 f.	.....
20.		22·7 vf.	.....	.....	.....	22·4	.....	22·1 f.	.....	.....	.....
21.		24·4 *	24·2 * w.	24·5 *	23·5 *	24·4	24 *	24·1 c.	23·3 b.	23 b.	23·5 b.
			1 f. here.								
22.		27·4 vf.	.....	.....	.....	26·4	.....	26·4 f.	.....	25·2 b.	28
23.		31·8 n.vb. 32·8 vn.	31 vf.	30·5 vnb.	29 w²f.	32·4 c.	30 b.	30·8 c.	.....	30·2 b.	31 f.
24.		34·1 *	.....	33 *	35 f.	34·4 *	.....	33·4 *	.....	33 *	34 f.
25.		36·6 b.	.....	37 b.	37·5 c.	37·4 c.	.....	35·8 b.	36·8 b.vn.	35·7 c.	.....
26.		39·4 b.	39·5 vf.	38·5 b.	.....	.....	39 c.	.....	.....	.....	.....
27.		41·4 b.	.....	41·5 vb.	41 nc.	41·4 b.	42 c.	40·6 *	40·8 * n.	41·5	43
28.		45·4 bn.	44·2 wb.	45 *	44·5 bw¹·²	45·4 f.	45 b.	.....	45·8 f.	45·8 f.	.....
29.		47·4 bn.	.....	46 *	.....	.....	.....	.....	.....	.....	.....
30.		49·3 f.	.....	49 f.	.....	48·9 f.	.....	.....	.....	.....	49
31.		.....	51·5 f.	50·5 f.	50·5 cn.	.....	51 b.	.....	49·8 f.	.....	.....
32.		52·6 *	53·5 vf.	53·5 f.	.....	52·4 *	.....	52 c.	.....	52 c.	53 b.
33.		54 vnc.	.....	.....	.....	54·4 c.	.....	54 c.	.....	54·8 *	.....
34.		56·6 *	55·5 f.	55·5 *	55 b.	56·4 *	55 b.	56 double c.	55·3 f.	56·8 f.	.....
35.	33	57·6 *	.....	58 *	.....	58·1 f.	.....	58·5 b.	.....	59·2 *	59 b.
36.	34	0 *	0·7 f.	.....	.....	59·4 *	1 b.	0·4 f.	59·8 f.	.....	.....
37.		2·6 nc.	.....	1·5 f.	1·5 b.	.....	.....	1·7 f.	.....	.....	.....
38.	λ	4·6 nb.	.....	3·5 c.	.....	.....	.....	3·6 c.	.....	3 f.	.....
40.		6·2 nc.	.....	5·5 f.	.....	.....	.....	4·9 c.	.....	many here n.	6 b.
41.		.....	8·5 wb.	.....	7·5	8·9	9 b.	7·8 c.	7·3	.....	.....
42.	μ	10·5 *	.....	10·5 b.	.....	.....	.....	10·1 b.	.....	10 f.	.....
43.	μ′	12·4 b.	.....	11·5 b.	.....	11·4	.....	10·8 c.	12·8 f.	.....	.....
44.	μ″	14 b.	13·5 f.	14 f.	14 b.	13·9 b.	.....	13·4 c.	.....	.....	13 b.
45.		15·4 f. 18 f.	.....	17 n.	.....	16·9 c.	16 b.	16·7 f.	.....	16·5 b.	.....
46.		20 vb.	19·7 wc.	20 c.	20 b.	19·4 *	.....	19·3 *	19·8 c.	19·8 b.	18 b.
47.		21·9 f.	.....	.....	.....	21·4 f.	21 b.	.....	.....	21 c.	.....
48.		26·2 f.	27·9 f.	26·5	.....	25·4 b.	.....	25·8	26·3 f.	25·3 b.	25 c.
49.	ξ	30·1 *	.....	30 *	28 b.	29·4 f.	28 b.	29·5	.....	28·2 f.	.....
50.		33 f.	.....	34 f.	34 nc.	34·4 *	34 b.	33·4 f.	34·3 f.	34 f.	32 f.
51.		36·3 wc.	36·6 vf.	36·5 c.	.....	.....	.....	.....	.....	.....	.....
52.		38·2 vf.	.....	40 f.	41 f.	.....	40·5 f.	.....	.....	38 f.	38 f.
53.		41·6 vf.	.....	43 f.	.....	42·4 f.	.....	.....	.....	43 f.	.....
54.		44·9 f.	.....	.....	.....	.....	.....	.....	.....	45 f.	.....
55.		48·2 f.	.....	48 f.	.....	48·4 f.	.....	.....	.....	47 c.	48 f.
56.		52·1 c.	.....	.....	.....	.....	.....	.....	.....	51 f.	55 f.
57.		57·4 vf.	.....	.....	.....	.....	.....	.....	.....	57 f.	69 f.

The first of these, air, C.P., was taken with Duboscq, and after the telescope had been improved; when first taken it showed only twenty-five lines, of which the groups ζ and λ were seen as broad bright bands. Air R. was taken at the same time, the others,

except H, C.P. (which was taken with Duboscq, and at the negative boundary) were with Merz, but with the improved telescope. As first observed, and at the centre, this last showed only eight lines.

It will be remarked that all the lines in the C.P. of nitrogen, and all but one in that of oxygen, are found in air, as might be expected; often a line is common to the three, and then that in air is of intermediate character. But the same line is also often found in the other two gases. It is generally supposed that this indicates the metallic origin of that line; but it will be found that many occur, not only in all these gases, but with all or nearly all the electrodes which I have tried. I shall return to this at another time, now making a few remarks on those before us.

The pair α, α' are of almost universal occurrence at the origin of the spectrum; α has close before it a narrow but bright companion, whose place has sometimes been taken; but outside of that there are merely shadowy traces scarcely ever bright enough to be bisected. In a very few cases, however, one of them becomes predominant, *e. g.* silver and iron. In H (hydrogen) spectra, one of this pair acquires an intense brilliancy, which is peculiar to this gas, while the other fades away. It is to be noted that α is exactly in the place of the solar line C. These and β, β' are in the red. No. 7, γ is an orange band, nearly but, I think, not exactly in the place of D. When viewed with the combination 2BS.C, it is double in all cases which I have examined; but the distance of the centres of its components is fully twice that of the components of D. No. 11, δ is yellow, generally extremely brilliant, except in one; it is seen in 2BS.C double, the second one being about half the breadth of the preceding. Before it is a narrow orange line, and before that No. 10, which *seems to attend it constantly*. Nos. 14 ϵ, the origin of green, 15 ϵ' and 16 ϵ'' are of constant recurrence. With the higher prism-power the first and third are each double, and some between ϵ' and ϵ'', of which one (as here in air, C.P.) has been occasionally observed. No. 18, ζ was at first observed as a bright cloudy band; 2BS.C shows that the whole of that region is covered with close lines, of which one is more conspicuous than the rest. In CO many more are conspicuous. No. 21, η is very brilliant (except in oxygen and CO, when its following companion is the brightest). With 2BS.C it is close double of two equal*. This is also the case with No. 24, θ, at the boundary between green and blue, which is, as a rule, the most intensely bright in all the C.P. spectra, in many of which its light is almost blinding. In R it is always faint though present. It is preceded by two narrow ones of unequal brightness, which seem to form with it a system. Another system seems to be found from 32 to $\varkappa''$ 36, remarkable for its beauty and peculiar character; $\varkappa'$ is vivid blue, close double of equals, $\varkappa''$, broad and cloudy, begins the violet. With 2BS.C $\varkappa$ is composed of two further apart, and $\varkappa''$ of six. It is less developed in nitrogen and H; λ 37·40 was at first observed as a band; in CO the whole of its vicinity is covered with narrow violet lines. The pair 28, 29, and the triplet μ, μ', μ'', are also of very constant occurrence.

* It has the deviation of b, and is double like it. No. 27 has that of F.

Table II.—Platinum.

		Air.		Nitrogen.		Oxygen.		Hydrogen.		Carb. oxide.		Mercury vapour.	Phospho-rus.	Bisulph. carbon.
		C.P.	R.	C.P.	R.	C.P.	R.	C.P.	R.	C.P.	R.			
1.	32	38·6 cna.	.....	.....	.....	38·6 f.	.....	37·5 w o.	.....	37 fo.	.....	.....	.....	Pressure. 0in·45
2.	α	30·7 vb.	.....	39·5 s	.....	40·8 f.	.....	.....	.....	.....	.....	.....	.....	.....
	α′	41·4 n.	.....	41 vn.	.....									
3.		42·4 f.	.....	.....	.....	44·3 f.	.....	.....	.....	.....	.....	.....	.....	.....
4.	β	47·1 f.	.....	48 f.	.....	47·6 s	.....	.....	.....	46 n.	.....	.....	.....	.....
5.	β′	48·9 vb.	.....	.....	.....	48·8 nb.	.....	.....	.....	.....	.....	49·4 f.	.....	.....
6.		50·2 f.	51·4 vf.	.....	.....	.....	.....	.....	.....	.....	50·5 vf.	51·4 b.	50·1 f.	.....
7.		52·8 f.	.....	.....	52 f.	.....	52·8 b.	.....	.....	.....	.....	.....	.....	51·7 f.
8.	γ	55·2 s	.....	55 s	55·5 f.	.....	55·8 nf.	.....	54 vf.	.....	55·5 nf.	55·5 f.	.....	.....
9.		56·4 nf.	56·7 vf.	.....	.....	.....	.....	.....	.....	56 vn.	.....	.....	.....	56·7 f.
10.	33	57·7 nf.	.....	.....	58 f.	.....	58·8 nf.	.....	.....	57 i.	59·5 vf.	.....	.....	.....
		59·4 nf.												
11.	33	0·7 n.	.....	.....	.....	.....	.....	.....	.....	.....	.....	0 s	0 f.	59·6 s
		1·4 n.												
12.		2·7 nb.	2·8 nf.	2·2 n.	2·5 f.	.....	.....	.....	.....	3 b.	.....	.....	.....	3·3
13.		3·9 s	.....	3 s	.....	.....	3·6 f.	3 f.	.....	4 b.	3·5 vf.	3·4 o.	.....	4 f.
14.		6·7 vf.	.....	.....	6 o.	.....	6·8 b.	.....	.....	5·5 vn.	7 f.	6·7 s	.....	6·7 s
15.	ε	9 vb.	.....	9·6 vb.	.....	.....	.....	.....	.....	many	.....	.....	.....	8 f.
16.	ε′	10·2 b.	10 f.	10 b.	.....	.....	.....	.....	.....	close and	.....	.....	.....	9·7 f.
17.		11·1 bn.	very faint	...	.....	.....	.....	.....	.....	narrow	.....	.....	.....	.....
		11·8 vn.	group	...	.....	.....	.....	.....	.....	here till	.....	.....	.....	.....
18.	ε″	12·4 b.	here.	12 b.	12 vf.	12·8 wb.	.....	.....	.....	.....	.....	11·7 s	11·4 s	12 s
				twof. here										
19.		14·4 vf.	15·4 f.	.....	15 vf.	14·8 en.	15·3 w²f.	.....	.....	.....	15 w²f.	14·7 f.	.....	.....
20.	ζ	16·4 vn.												
		17·4 vn.	17·7 vf.	17 b.	.....	16·8 b.	.....	.....	.....	.....	.....	16·8 f.	19·7 o.	16·7 f.
		18·8 b.												
21.		.....	21·7 vf.	20·5 f.	20 f.	.....	19·8 f.	.....	.....	21 vn.	19 vf.	20·7	20·1 f.	20·7 b.
22.		24·4 s	.....	24 s	24 s	23·8 fn.	24·3 b.	23 vf.	22 vf.	23 vnc.	23 b.	24·1 s	24·1 f.	24·1 b.
23.		27·8 n.	26·1 vf.	.....	.....	.....	.....	.....	.....	11 or 12	25 vf.	25·7 f.	.....	.....
										here.				
24.		31·6 nb.	30·1 f.	30·8 nb.	29 f.	.....	29·3 f.	.....	.....	30 vnc.	28 f.	30·1 f.	.....	28·7 f.
25.		32·8 vn.	31·4 f.	32·3 s	33 vf.	32·3 f.	.....	.....	.....	32·5 s	.....	.....	.....	31·8 f.
26.		34 s	.....	.....	.....	.....	.....	.....	.....	35 f.	35 vf.	34 f.	.....	34·1 f.
27.		37·2 o.	35·8 nf.	37 wb.	.....	36·8 bn.	.....	36·8	.....	.....	.....	36·1 f.	.....	.....
28.		39·5 o.	38·1 o.	.....	38·5 f.	39·3 bn.	.....	39·5 s w.	39·5 s?	.....	.....	37·5	38·1 o.	38·1 o.
29.		41·5 ow.	41 vf. rn.	40·7 sw².	.....	41·8 b	40·8 nb.	.....	.....	40 wb.	38·5 f.	40·1 f.	42·1 f.	41·4 f.
30.		45·1 b.	44·7 b.	45 b.	45 s	.....	43·8 b.	.....	.....	44 vn.	43 o.	44 s	44·1 f.	44·1 s
31.		46·6 b.	.....	46 b.	.....	.....	.....	.....	.....	45 f.	.....	.....	46·4 f.	.....
32.		49·4 f.	48 vn. f.	50 o.	50 f.	.....	.....	.....	.....	48 vnf.	.....	.....	.....	49
										50 s				
33.		51·9 vb.	51 f.	51 c.	.....	51·8 s	52·3 vf.	.....	.....	51 f.	51·5 vf.	.....	.....	three f.
		double.												here.
34.		53·8 nc.	.....	53 c.	.....	53·8 nc.	.....	.....	.....	53 s	.....	.....	.....	.....
35.		56·1 s	55·3 c.	55 s	55 f.	55·6 s	.....	.....	.....	56 f.	.....	.....	55 f.	55 b.
			double.											
36.		57·1 s	.....	56 s	.....	.....	.....	56·5 nb.	.....	57 s	.....	.....	.....	.....
37.	33	59·1 s	.....	58 s	.....	58·8 s	.....	.....	.....	.....	.....	58·8 f.	57·6 o.	.....
38.	33	.....	1·1 ow.	.....	0 f.	.....	0·8 f.	.....	.....	0 f.	1 vf.	1 f.	.....	.....
39.		2·3 b.	.....	2 b.?	.....	.....	.....	.....	.....	2 f.	.....	.....	.....	.....
40.	λ	4·1 b.	.....	3 b.?	.....	.....	.....	.....	.....	4·5 f.	.....	.....	.....	.....
41.		5·6 b.	.....	5 f.	5·5 f.	.....	5·8 b.	.....	.....	5 f.	6 b.	.....	.....	.....
42.		.....	7·6 ow.	6 f.	6 f.	8·6 b.	.....	.....	.....	7 f.	.....	6·5 s	6·2 f.	6·2 o.
43.	μ	10·8 s	.....	11 b.	.....	.....	.....	.....	.....	9 f.	.....	9·1 vf.	.....	.....
44.	μ′	12·3 b.	.....	12 b.	13 f.	12·6 b.	.....	.....	.....	12·5 b.	.....	12·4 f.	.....	.....
45.	μ″	13·6 b.	13·4 ow.	13·2 b.	14 f.	.....	.....	.....	.....	.....	.....	.....	.....	.....
		15·4 f.	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
46.		17·7 o.	.....	16·8 b.	16·5 f.	16·2 f.	14·8 b.	.....	.....	18 o.	17·7 wf.	16 vnc.	.....	.....
				double.							seems			
											triple.			
47.		19·3 b.	19·9 ow.	20 o.	20 b.	18·8 f.	18·8 f.	20 s w.	19·5 f.	19·5 f.	.....	18·6 s	18·6 s	18·3 s
48.		22 o.	.....	22·2 f.	.....	21·8 f.	22·8 f.			.....	.....	.....	.....	22·2 o.
49.		25·9 n.	27·2 ow.	26 o.	27·5 o.	25·8	some f.	.....	.....	25 s	25 f.	.....	.....	24·5 f.
							seen here.							
50.		30 vb.	30·1 vnf.	30 s	.....	.....	.....	.....	.....	28 f.	.....	30·1 f.	.....	.....
51.		33·3 n.	.....	33 f.	34 f.	.....	.....	.....	.....	33 f.	33 f.	.....	.....	.....
52.		35·1 vf.	35 nvf.	.....	.....	34·6 o.	.....	.....	.....	34 f.	.....	.....	.....	35 f.
53.		36·2 c.	.....	36 f.	.....	.....	.....	.....	.....	36 f.	.....	.....	.....	.....
54.		39·1 nc.	.....	39 f.	.....	.....	.....	.....	.....	38 f.	.....	.....	.....	.....
55.		41·7 nc.	.....	.....	42 vf.	.....	41·8 f.	.....	.....	41 f.	41·5 f.	42·8 vf.	.....	.....
56.		45 nc.	.....	45 f.	.....	.....	.....	.....	.....	44 f.	.....	.....	.....	.....
57.		48·3 f.	49·5 vf.	48 f.	.....	.....	.....	.....	.....	47 f.	48·5	46·9 fv.	.....	46·7 f.
58.		51·5 f.		52·2 c.	.....	.....	.....	.....	.....	50·5 f.	49·2 f.	50·9 fv.	.....	50·8 f.
59.		58·2 vf.	.....	56 f.	.....	58·8 f.	.....	.....	.....	56 f.			.....	

In the air C.P. and R. were observed with Duboscq and are therefore comparable with the aluminium air spectra. So also were those of Hg, P, and S°C. In the mercurial vapour the discharge was bright, greenish white, with very large cloudy strata; the spark discharge without the jar gave exactly the same spectrum. It has more *s than oxygen or carb. oxide; but the rest of it is very dark. In the phosphorus and bisulphuret the tubes were so darkened by deposit as to make observation difficult; the first was red, I suppose allotropic P, for nothing would remove it but strong nitric acid; the other is partly black (I suppose sulphuret of Hg), partly grey arranged in striæ (perhaps carbon). The P spectrum is so like that of Hg vapour, that I think it exerted very little influence, and in the other the metallic vapour seems also to predominate. I also tried olive oil in the same apparatus to ascertain whether its vapour (which may be present in air-pump experiments) could produce any effect. The flash of the discharge was bright green, as in the CO and S°C tubes; but this probably came from the decomposition of a film of oil on the electrodes: the spectrum was identical with Hg vapour, except that it was very faint.

TABLE III.—Silver.

		Air.				Nitrogen.		Oxygen.		Hydrogen.		Carb. oxide.	
		Spark C.P.	J. C.P.	C.P.	R.	C.P.	R.	C.P.	R.	C.P.	R.	C.P.	R.
1.	33	37·4 vf.	36·5 * double.	.....	.....	.....	36·5 c. double.	.....	.....	37 *	.....	.....	.....
2.	α	.....	.....	38·8 * double.	.....	.....	.....	38·5 *	.....	.....	.....	.....	.....
3.	α′	.....	40 b.	40·8 *	41 c.	40 *	.....	41 f.	39·5 c.	.....	.....	40·5 *	.....
4.		.....	42·5 f.	.....	.....	41·5 f.	.....	.....	.....	.....	.....	.....	.....
5.	β	.....	46 f.	.....	.....	.....	.....	45·5 f.	.....	.....	.....	.....	.....
6.	β′	.....	49 b.	47·8 b.	.....	49 f.	.....	48 *	.....	.....	.....	49·5 b.	.....
7.		51·4 b.	.....	.....	51·5 f.	.....	51·5	.....	51 f.	.....	50·5 f.	51·5 c.	52 *vr[1·2]
8.	γ	.....	56 *	55·8 *	.....	55 *	56 f.	55 c.	.....	.....	.....	56·5 f.	56 f.
9.	32	.....	58 *	.....	59 f.	.....	59 f.	.....	.....	.....	58·5 f.	57·5 *	.....
10	33	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0·5 f.	0 f.
11.		4·3 *	4 c.	3·8 c.	.....	3 c.	3·5 f.	3 c.	3 f.	3 f.	.....	.....	.....
12.	δ	.....	5 *	4·8 *	.....	4 *	.....	.....	.....	.....	.....	5·5 b.	4 f.
13.		6·7 vf.	6 f.	.....	6·5 *	.....	.....	.....	6·5 *	.....	7	7 f.	7 *
14.	ε	8·7 b.	9 b.	8·8 b.	.....	.....	8	8 f.	.....	.....	.....	three	.....
15.	ε′	.....	11 c.	10·8 b.	.....	10 b.	.....	.....	.....	.....	11 b.	9·5 f.	.....
16.	ε″	not taken.	12 *	11·3 b.	.....	12 b.	.....	12·5 c. close pair	.....	.....	.....	three	.....
17.		.....	14 b.	13·8 c.	14 b.	13 b.	13 c.	.....	13 f.	.....	.....	14·5	f. .....
18.	ζ	.....	18 f.	17·8 b.	.....	15·5 c. 17·5 c.	17 b.	17 *	18·5 f.	.....	.....	three	16 f.
19.		20·7 b.	.....	.....	.....	19 c.	.....	.....	.....	.....	.....	19·5	f. .....
20.		.....	22 b.	22·0 c.	.....	22 vnc.	21 f.	22	.....	.....	22·5	21·5 c.	21·5 f.
21.	η	.....	24	24·8 *	23·5 *	24 *	.....	24·5	24 *	23 f.	23·5	24·5 c.	.....
22.		.....	.....	.....	.....	.....	25 *	26	.....	.....	.....	26 *	25 *
23.		30·8 nb.	29	30·8 c.	29·5 f.	32 nc.	30	30 f.	29 b.	31·5 f.	.....	30	30 f.
24.	θ	33·5 *	33·5 *	33·8 *	.....	34·5 *	35 f.	33·5 b.	32 b. 34 b.	.....	.....	33·4 b. 34·6 b.	35 f.
25.		37 f.	35 c. 37 c.	36·8 f.	.....	38 b.	39 b.	37 b.	38 b.	.....	.....	37·5 f.	36 f.
26.		41·4	41	40·8 f.	41 c.	40·5 f.	41·5 f.	41 *	40 b.	39 *	40 *	.....	40 f.
27.		.....	.....	44·8 b.	42·5 *	43 b.	44·5 f.	.....	44 b.	.....	42 f.	42·5 b.	44 f.
28.		46 b.	47 c.	46·8 b.	.....	46 b.	.....	46 f.	.....	.....	.....	.....	.....
29.		.....	.....	.....	.....	47·5 b.	.....	.....	.....	.....	.....	48 c.	.....
30.		50·7 b.	49 * double.	50·8 c.	51	50 f.	51	50 *	50 b.	.....	.....	50·5	.....
31.	ι	.....	.....	.....	.....	52 b.	.....	52·5 f.	.....	52·5 c.	52 f.	52·5 *	53 f.
32.		.....	54 b.	.....	.....	54·5 b.	55	55 *	53·5 b.	.....	.....	54·5 c.	.....

TABLE III. (continued).

		Air.				Nitrogen.		Oxygen.		Hydrogen.		Carb. oxide.	
		Spark C.P.	J. C.P.	C.P.	R.	C.P.	R.	C.P.	R.	C.P.	R.	C.P.	R.
33.	° *	5·3 b. double.	.....	5·8 * double.	.....	5·6 *	.....	narrow one here.	.....	.....	.....	5·5 * double.	.....
34.	ε′		5·8 *	.....	.....	5·7 *	.....	.....	.....	.....	.....	5·7 vn.	.....
35.	33 ε″	5·8·5 b.	.....	5·9 *	.....	5·9 *	.....	5·8 *	0 b.	.....	.....	0 *	5·9
36.	34	1·1 vf.	.....	.....	.....	.....	1·5	2 b.	.....	.....	.....	.....	.....
37.	λ	4·2 vf.	.....	3·3 b.	.....	3 b.	.....	.....	.....	.....	.....	.....	3 f.
38.		.....	.....	.....	6	5 *	7·5	.....	6	.....	5 f.	.....	.....
39.		9·8 b.	8 b.	.....	.....	.....	.....	.....	.....	.....	.....	8 others 10·5 } f. f.	7 *
40.	μ	10·8 f.	9 b.	10·8 *	.....	10·5 b.	.....	9·5 f.	.....	.....	.....	.....	.....
41.	μ′	12·1 f.	11 b.	11·8 b.	.....	12 b.	.....	11·5 f.	.....	.....	.....	13·5 b.	.....
42.	μ″	14·4 f.	14 f.	14 b.	14·3 f.	.....	14·3	13·5 f.	13 b.	.....	.....	13·5 b.	.....
43.		.....	16 c.	17·8 b.	.....	17 f.	.....	16 c.	.....	15·5 *	.....	18·5 c.	17 f.
44.	,	20 f.	19 f.	19·8 f.	.....	19·5 c.	20·5	19 b.	19 b.	.....	.....	20·5 c.	.....
45.		some seen.	22 f.	.....	22 f.	.....	.....	22 f.	.....	.....	.....	23 c.	.....
46.		.....	25 b.	24·8 f.	.....	26 f.	.....	25 f.	25·5 b.	.....	.....	.....	.....
47.		29·1 f.	29 f.	27·8 b.	.....	.....	28 f.	.....	.....	.....	.....	27·5 *	.....
48.	ξ	.....	31 f.	.....	.....	30 b.	.....	29·5 *	.....	.....	.....	.....	.....
49.			.....	33·3 f.	33·5 f.	32 f.	.....	.....	.....	.....	.....	.....	.....
50.	34	36 vf.	.....	.....	.....	37 c.	35 vf.	35 f.	.....	.....	.....	36 c.	.....
51.			41 f.	.....	.....		41 vf.		39·5	.....	.....	39·5 vf.	.....
52.		.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	43·5 vf.	.....
53.		.....	46·5 f.	.....	.....	.....	.....	.....	.....	.....	.....	48·5 vf.	.....

These C.P. spectra are of very great splendour; the ground, especially the green part, is far brighter than the preceding, and the lines are dazzling. The R ones are on the whole faint. The first is a simple spark (without jar): it differs little except in brightness. The second, headed J, was obtained with two large jars having 8·5 feet of external coating; it was far more luminous, and showed eight more lines than the normal one, besides four at the violet end, which were measured, but not tabulated, as they were not seen in the other spectra. I was struck with the outline of this spectrum, which gives an idea that the red and violet rays are less abundant near the electrodes. [See p. 973.]

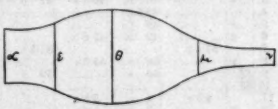

TABLE IV.—Copper.

		Air.		Nitrogen.		Oxygen.		Hydrogen.		Carb. oxide.	
		C.P.	R.	C.P.	R.	C.P.	R.	C.P.	R.	C.P.	R.
1.	33	37·1 nc.	.....	36·5 *	.....	.....	.....	.....	.....	.....	.....
2.	ε	38·2 *	.....	38·5 b.	.....	38·3 b.	.....	.....	.....	38·3 *	.....
3.	ε′	39·6 vb.	.....	40·5 f.	.....	41·3 f.	.....	40 * o.	39·8 o.b.	.....	.....
4.		.....	.....	43·5 f.	.....	.....	.....	.....	.....	.....	.....
5.	β	47·8 *	.....	46 b.	.....	48·3	.....	.....	.....	47·8 f.	.....
6.	β′	.....	50 f.	.....	49·5 f.	50·3 f.	50·3 f.	.....	50·4 f.	49·5 *	51·5 c.
7.	γ	54·2 *	.....	53 *	52·5 f.	54·8 vf.	.....	.....	.....	55·5 c.	54·5 f.
8.		.....	.....	.....	57·5 o.	.....	.....	.....	.....	56 *	.....
9.	32	59 f. many here.	58·5 f.	59·5 c.	60·5 f.	.....	.....	.....	59 c.	58·5 f.	58·5 f.
10.	33	1·5 f.	2 f.	1 *	.....	.....	1·8 f.	.....	.....	0·8 f. 2·6 f. } 3·9 f.	2·5 f.
11.		4·1 *	.....	.....	.....	3·8 c.	.....	.....	3·5 c.	.....	.....
12.		.....	6 b.	6·5 b.	5 b.	.....	6·8	.....	7 b.	5·8 about 30 n here.	5·5 * 7·5 *
13.	,	8·4 *	.....	8·5 c.	.....	8·3 f.	.....	.....	.....		

TABLE IV. (continued).

		Air.		Nitrogen.		Oxygen.		Hydrogen.		Carb. oxide.	
		C.P.	R.	C.P.	R.	C.P.	R.	C.P.	R.	C.P.	R.
14.	° ′	9·8 vb.	.....	two.	.....	.....	.....	.....	.....	.....	.....
15.	′ ″	11 vb. many.	11 c.	10·5 c.	10·5 c.	12·3 b.	.....	.....	12 f.	.....	11 c.
16.		.....	.....	14·2 f.	14·5 f.	14·3 f.	14·8 f.	.....	14·5 bw.	.....	.....
17.		.....	.....	.....	.....	16·3	.....	.....	.....	.....	15·5
18.	ζ	18·5 b.	.....	.....	19 f.	20·8	19·8 f.	.....	20 c.	19·8 b.	19·5 f.
19.		21·7 vb.	23	22 *	.....	.....	22·8 b.	.....	.....	22·3 b.	23·5 f.
20.	*	24·3 *	23·5	.....	24·5 *	23·3	.....	.....	24·6 b.	.....	24·5 f.
21.		25 c.	.....	25·5 f.	25·5 f.	25·3	.....	.....	.....	26 *	.....
22.		27 c.	.....	28·5 c.	27 f.	.....	28·8 f.	.....	28·5 vnf.	26·5 c.	28·5 f.
23.		30·5 c.	.....	30·5 *	31·5 f.	.....	.....	.....	.....	30·1 c.	.....
24.	′	32·9 *	.....	.....	.....	32·8 b.	.....	33·5 f.	32·8 f.	33·3 c.	33·5 f.
25.		35·5 b.	.....	35·5 f.	.....	.....	.....	.....	.....	35·8 b.	.....
26.		36·8 b.	.....	.....	36 f.	36·3 b.	.....	.....	37·4 vf.	.....	.....
27.		38·1 b.	.....	38·5 b.	.....	.....	.....	.....	.....	.....	38·5 f.
28.		40	.....	42·5 b.	41·5	41·3 b.	39·8 c.	41·5 *	.....	41 b.	.....
29.		44 b.	43·5 b.	43·5 b.	.....	.....	43·8 c.	.....	43·6 b.	.....	43 *
											44 f.
30.		46 b.	.....	48·5 f.	47·5 f.	.....	.....	.....	.....	46·3 f.	.....
										48·9 f.	.....
31.		51 b.	.....	50·5 f.	51·5 f.	50·3 *	.....	.....	51·9 f.	50·3 *	.....
32.	,	.....	.....	52·5 c.	.....	51·3 c.	.....	.....	.....	52·3 c.	52 f.
33.		.....	53 f.	53·5 *	.....	53·8 *	.....	.....	.....	.....	.....
34.	≈	55·4 *	.....	55·5 *	.....	.....	.....	55·5 vf.	.....	54·5 *	.....
35.	″	56·6 *	.....	.....	.....	.....	.....	.....	.....	56·8 f.	.....
36.	33″	58·5 w*	.....	59·5 c.	58 f.	57·3 *	.....	.....	59·8 f.	58·9 *	59·5 f.
37.	34	.....	.....	1·5 c.	.....	.....	.....	.....	.....	0·7 f.	.....
				2·5 f.						about 20 here.	5·5 b.
38.	λ	3·5 b.	.....	.....	.....	3·3 f.	4·8 f.	.....	.....	.....	
39.		.....	6·5 b.	8·5 *	6·5	8·3 f.	.....	.....	6·9 b.	8·5 f.	.....
40.	μ	10·1 *	.....	10·5 b.	10·5 f.	.....	.....	.....	.....	10·9	.....
41.	μ′	11 b.	.....	12·5 f.	12·5 f.	11·8 *	.....	.....	.....	.....	.....
42.	μ″	13·4 vb.	.....	14·5 f.	15·5 f.	15·3 f.	.....	.....	.....	13·8 f.	14·5 f. about 20
43.		16·7 c.	17	16·5 f.	17·5 f.	17·3 f.	17·8	.....	16·8 f.	16·3 f.	..... f.
44.		18·7 vb. two on each side.	some beyond.	.....	.....	19·3 f.	.....	18·8 *w.	.....	18·5 f.	18 f.
45.	ν	.....	.....	20 f.	.....	.....	.....	.....	.....	20·5 f.	.....
46.		22·6 w*	.....	24·5 f.	24·5 b.	24·3 f.	.....	.....	22·3 b.	.....	.....
47.		25·8	.....	.....	25·5 b.	double.	.....	.....	.....	25·5 *	.....
48.	ξ	29 b.	.....	27·5 *	.....	.....	.....	.....	.....	.....	.....
49.		many here.	.....	31·5 c.	31 f.	32·3 c.	.....	.....	.....	32·5 c.	.....
50.	ο	36 f.	.....	34·5 c.	.....	35·3 f.	.....	.....	.....	37·5 f.	.....
51.		.....	.....	.....	40 f.	38·8 f.	.....	.....	38·8 vf.	37·5	.....
52.		.....	.....	43 c.	.....	41·3 f.	.....	.....	.....	41·5 f.	42·5
53.		47·5 vf.	.....	50·3 c.	46 vf.	45·8	.....	45·3 vf.	.....	45 f.	
										47·5 c.	.....

In these the most remarkable thing is the comparative dullness of the red and yellow. In O, C.P., there seems no yellow, but the green ground is so intense that the lines there are scarcely visible. In O, R., the flash is green; in CO, C.P., is the same dullness of the red, but the faint ultra violet are visible in great numbers. In this also there are countless fine lines in the blue, and still more in the green.

TABLE V.—Nickel.

		Air.		Nitrogen.		Oxygen.		Hydrogen.		Carb. oxide.	
		C.P.	R.	C.P.	R.	C.P.	R.	C.P.	R.	C.P.	R.
1.	32	.....	.....	.....	33·9 vf.	.....	.....	.....	.....	.....	.....
2.	α	39 *	.....	38·4 *	.....	38·5 *	38 vnfo.	39·7 *	.....	38·5	.....
3.	α′	40·6 nb.	.....	40	.....	.....	.....	.....	.....	.....	.....
4.		43 c.	.....	43·6 f.	.....	42 vf.	42 fo.	.....	.....	41·5 vf.	.....
5.	β	46 f.	.....	45·5 f.	.....	43·5 vf.	46·5 fo.	.....	.....	46 vf.	.....
6.	β′	49 *	.....	48·1 *	.....	48 *	.....	.....	.....	48·5 *	48 ovf.
7.		.....	.....	.....	50·4 vf.	49·5 nf.	51 f.	.....	50·7 f.	50·5 vb.	.....
					51·4 vf.						
8.		.....	52·2 f.	52·7 vf.	52·7 vf.	.....	.....	.....	.....	.....	52
9.	γ	55 *	.....	55 *	54·3 vf.	55·5 f.	54 vf.	.....	.....	.....	.....
10.		56·5 nb.	.....	.....	56 vf.	.....	.....	.....	.....	56·5 *	57 f.
11.	32	.....	60·2 vf.	.....	58·3 vf.	59 vf.	59 f.	.....	59·7 vf.	58·8f.	60 f.
					59·3 vf.						
12.	33	2 nb.	.....	2 nb.	1·3 vf.	3 bw[2].	2·5 f.	.....	.....	3 b.	.....
13.	3	4 *	.....	4 *	.....	.....	5·5 *	3·7 n.	.....	4·5 b.	5 f.
14.		6 f.	.....	.....	6 f.	6 cw.	6·5 n.	.....	.....	6·5 b.	.....
15.	ε	8 b.	7·2 c.	8·7 vb.	7·3 f.	.....	.....	.....	7·7 f.	8·5 b.	8 *
		9 n.									
16.		9·5 n.	.....	.....	9·7 f.	.....	.....	.....	.....	..... b.	9 n.
17.	ε′	10·5 nb.	.....	10 b.	11 c.	10·5 c.	10 vf.	.....	.....	10·5 b.	.....
18.	ε″	.....	.....	12 b.	12·7 f.	.....	.....	.....	.....	12·5 b.	12 vf.
19.		.....	14·2 triple.	.....	14·7 f. 15·4 f.	15·5 c.	14 wf.	.....	14·2 wf.	14·5 b.	.....
20.	ζ	16·2 bw[2].	.....	17·2 bw[4].	17·4 f.	.....	.....	.....	.....	17·5 b.	17 w[4].
21.		19 bw.	.....	.....	18·7 nc.	19 c.	19 wf.	.....	.....	20·5 b. both double.	21 f.
22.		23 *	.....	.....	.....	21·5 *	23 *	.....	.....	22·5 b.	.....
23.	η	25 vn.b.	24·7 c.	24·7 *	24·7 b.	25 *	.....	.....	.....	.....	.....
24.		26 vn.b.	.....	.....	.....	26 n.	.....	.....	.....	.....	.....
25.		28 vn.b.	.....	27·7 vf.	.....	29 f.	28 vf.	.....	29·2 n.	29·5 f.	.....
26.		30 vn.b.	30·2 nb.	31·4 nb.	30·4 b.	.....	31·5 vf.	.....	.....	31·5 vf.	31 w[2]f.
27.	θ	32·5 *	.....	33·1 nf.	32·8 b.	32 f.	.....	32·2 n.	.....	32 f.	.....
28.		35 nb.	34·7 n.	33·4 * 36·4 f.	36·1 b.	36 nb. 37 vn.	34 nf.	.....	.....	36·5	35 vf.
29.		38 f.	39·2 n.	39·4 f.	39·4 b.	38·5	.....	.....	39·2 nb.	.....	39 vf.
30.		40 w[2]	.....	.....	.....	40 b.	40 nb.	40·7 ww[2].	.....	.....	41 vf.
31.		.....	.....	41·7 b.	42·1 nf.	.....	42 *	.....	42·2	41·5 wf.	42·5 *
32.		44 b.	.....	45·4 b.	.....	.....	.....	.....	.....	.....	44·5 b.
33.		45 b.	45·2 b.	46·7 b.	45·4 b.	46 vf.	46 f.	.....	.....	46 n.	.....
34.		48 f.	.....	48·7 f.	.....	48 n.	.....	.....	48·2 wc.	.....	.....
35.		50 b.	50·7 w.	50·7 vf.	50·7 b.	50 *	50 b.	.....	.....	49·5 no.	49 vf.
36.	ι	.....	.....	52 vf.	.....	53 nc.	.....	.....	52·2 wc.	51·5 *	.....
37.	κ	54·5 *	.....	54 nf.	54·7 b.	54·5 *	54 wb.	.....	.....	.....	53·5 f.
38.	κ′	55·5 *	55·2 w.	56 *	55·9 b.	56·5 n.	.....	55·2 nb.	.....	56 * double.	.....
39.	κ″	57 ow.	.....	57 *	.....	58 *	.....	.....	.....	58 n.	.....
40.	33	.....	.....	59 *	.....	.....	.....	.....	59·2 wc.	59·5 *	.....
41.	34	1 b.	.....	2·3 b.	1·7 b.	.....	0·5 b.	.....	.....	.....	.....
42.	λ	3 c.	2·2	4·2 b.	.....	.....	5 b.	.....	.....	.....	.....
43.		4 c.	.....	5·9 b.	.....	.....	6 b.	.....	5·7 wc.	.....	6·5 *
44.		6 f.	7·7 w.	9·2 f.	8·2 b.	7·5 nb.	.....	.....	.....	.....	.....
45.	μ	10·5 b.	.....	.....	.....	9·5 nb.	.....	.....	.....	9 b.	.....
46.	μ′	12 b.	.....	11·1 *	.....	12 *	.....	.....	12·7 wc.	11 b.	.....
47.	μ″	13 b.	14·7 n.	14·7 f.	14·1 b.	16 c.	15 b.	.....	.....	13 *	.....
48.		17 f.	.....	17 f.	18·3 nb.	17·5 *	18 vb.	17·4 w[2]f.	.....	17 b.	17 b.
49.		19 nb.	.....	19·3 f.	20 nb.	20 c.	21·5 nc.	.....	18·7 wc.	19 vb.	.....
50.	ν	22·7 f.	21·7 w.	22·6 vf.	.....	23 vf.	.....	.....	.....	22 b.	22·5 vf.
51.		25 f.	.....	25·5 vf.	.....	25·5 *	25 b.	.....	24·2 wc.	.....	.....
52.		28·5 b. w[2].	.....	27·5 vf.	27·2 b.	.....	.....	.....	.....	29 *	.....
53.	ξ	.....	29·7 w.	29·8 nb.	.....	.....	29 f.	.....	.....	.....	.....
54.		33·5 f. w[2].	.....	33·7 b.	34·1 b.	33 b.	33 nf.	.....	31·2 vf.	31·5 vf.	.....
55.	ο	.....	36·2 n.	36·3 b.	.....	38 f.	.....	.....	.....	36 b.	.....
56.		42·5 f.	.....	40·3 vf.	40·3 vf.	41 n.	40 nf.	.....	.....	42·5 c.	.....
57.		.....	.....	44·9 c.	44·9 vf.	43·5 c.	.....	.....	.....	45 c.	.....
58.		47·5 f.	.....	47·9	49·5 f.	47 b.	47 f.	.....	.....	49 vf.	.....
59.		51·5 vf.	.....	52·1 c.							

Of these the spectra N were taken with Duboscq.

The group 23–26, in air, C.P., is notable. In N, R., the remarkable set 7–12 were first recognized; they are very faint, as broad as the slit, and spread over the orange and yellow. The groups 14–16 and 18–20 are peculiar. In O, C.P., there is scarcely any yellow, and the lines from seven to twenty-eight are very indistinct, from the brightness of the ground.

TABLE VI.—Palladium.

		Air.		Nitrogen.		Oxygen.		Hydrogen.		Carb. oxide.	
		C.P.	R.	C.P.	R.	C.P.	R.	C.P.	R.	C.P.	R.
1.	33 α	39• double	.....	38·4 •	.....	.....	.....	.....	38·8 of.	.....	.....
2.	α'	.....	.....	39·7 b.	.....	40·3 of.	.....	39·5 o•	.....	39·7 • very intense	39·5 ovf.
3.		41·8 vn.	.....	41·6 f.	.....	.....	.....	.....	.....	.....	.....
4.	β	.....	.....	45·2 f.	.....	.....	.....	.....	.....	.....	.....
5.	β	48·5 b.	.....	47·5 •	.....	48·3 f.	.....	.....	.....	49·5 b.	48·5 ovf.
6.		.....	50·3 vf.	.....	51·4 f.	.....	51·9 vf.	.....	51·8 f.	51·5 b.	.....
7.		.....	.....	54 •	53·7 f.	.....	.....	.....	.....	.....	.....
8.	32 γ	56·3 •	.....	57·3 f.	56 f.	55·8 nb.	.....	.....	.....	57 •	56 f.
9.	33	.....	0·3 f.	59·6 f.	58 f.	.....	0·4 vf.	.....	58·8 f.	0 n.	1 f.
10.		3·3 nc.	.....	1·6 b.	0 f.	.....	.....	3 nf. double	2·8 vf.	.....	.....
11.	δ	4·3 •	.....	3 •	.....	4·3 nb.	.....	.....	.....	4 b.	.....
12.		.....	.....	5·3 f.	.....	.....	.....	6·5 nf.	.....	6 b.	5 f.
13.		.....	.....	6·3 b.	7·3 b.	.....	7·9 f.	.....	7 c.	7·5 f.	8 b.
14.		9·3 vn.	.....	10 b.	.....	9·8 c.	.....	9·5 nc.	.....	10 f.	9
15.	ε'	10·8 b.	.....	10·7 f.	.....	.....	.....	.....	.....	not distinct f.	.....
16.	ε''	12·3 b.	.....	11·4 b.	11·7 f.	11·3 c.	.....	.....	.....	..... f.	12 vf.
17.		.....	13·3 c.	14 f.	.....	13·8 c.	15·1 w².	15·6 vn.	13·8 f.	13 f.	.....
18.	ζ	17·3 wb.	17 w².	16·7 b.	17 f.	17·3	.....	18·5 nb.	17·8 vf.	16 f.	16 wf.
19.		.....	.....	21·4 f.	.....	.....	.....	21·5 fw.	.....	18 f. 19 f. 21 f.	21 n.
20.	η	24·8 •	.....	24·1 •	24·7 b.	24·8 c.	25·4 b.	25·5 nc.	23 b.	24 c.	25 •
21.		.....	27·3 wc.	27·4	.....	.....	.....	28 nc.	28 nc.	26 • double	27 f.
22.				30·8 b.	30·4 b.	.....	30·4 nc.	.....	.....	31 f.	.....
23.		31·7 nvb.	.....	31·4 b.	... b.	.....	.....	.....	.....	.....	.....
24.		.....	.....	32·8 •	32·8 b.	32·3 vnb.	.....	.....	.....	.....	.....
25.	θ	33·8 •	33·3 f.	.....	.....	34·3 •	.....	33·5 nb.	33 vf.	34 vf.	34·5 vf.
26.		36·8 f.	.....	36·4	36·1	37·3 nvb.	38·4 nf.	.....	37·5 nc.	37 c. many	.....
27.		.....	.....	38·8	39·4 b.	.....	.....	.....	.....	39·5 nf.	40 vf.
28.		41·3 b.	41·3 f.	40·7	41·4 f.	41·8 w².	41·9 f.	41·2 •w².	41 b. 43 b.	42 •	.....
29.		45·3 b.	.....	44·7 b.	43·4 b.	.....	.....	.....	45 b.	.....	44·5 •
30.		46·3 b.	.....	46 b.	45·4 b.	46·3 f. centre of 3	.....	.....	.....	.....	.....
31.		.....	47·3 wc.	48·7 f.	.....	.....	.....	.....	.....	47·5	47 •
32.		.....	.....	50 f.	.....	.....	50·4c.	.....	50·2 nc.	50 nc.	50·5 vf.
33.	ι	51·3 b.	.....	52 b.	51·3	51·8 nc.	.....	.....	.....	52 •	.....
34.		.....	54·3	54 b.	.....	.....	54·4 c.	.....	.....	54 nb.	54 vf.
35.	κ	56·3 •	.....	55·3 •	55·3	55·8 •	.....	.....	.....	55·5 •	.....
36.	κ'	double	.....	56·3 •	56·3	56·3 •	.....	.....	56 w.	.....	.....
37.		.....	.....	57·2 f.	.....	.....	.....	57·5 nf.	.....	58 n.	.....
38.	33 κ''	58·3 •	58·3	58·5 •	.....	59·3 •	.....	.....	.....	59·5 •	.....
39.	34	2·3 n.	.....	1·7 b.	2·3 b.	2·8 vnc.	1·4 c.	.....	.....	many here very sharp	.....
40.	λ	3·3 n.	.....	3·6 b.	.....	.....	.....	.....	.....	.....	.....
41.		4·3 n.	5·3	4·9 b.	.....	4·3 nb.	.....	4·5 nf.	.....	.....	4 f.
42.		.....	.....	7·2	8·8 b.	.....	7·4 c.	.....	8 w.	.....	7 •
43.	μ	9·8 b.	.....	10·1 •	.....	10·3 c.	.....	.....	.....	10 b.	.....
44.	μ'	11·8 b.	10·8	11·4 •	.....	11·8 c.	.....	12·5	.....	11·5 b.	.....
45.	μ''	13·3 b.	.....	13·4 f.	14·4 b.	14·3 c.	14·4 c.	.....	14 w.	14 •	13 vf.
46.		16·3 c.	.....	16 f.	.....	.....	.....	.....	.....	15·5 vf.	.....
47.		17·3 c.	17·3	.....	.....	17·3 nf.	.....	.....	.....	.....	.....
48.		18·3 c.	.....	18·6 f.	.....	.....	.....	.....	.....	18 b.	18 f.
49.	ν	.....	.....	20·9 f.	20 b.	19·3 c.	19·4	20·5 •w².	20 w.	19 b.	19 f.
50.				22·2 f.	.....	22·3 vf.	.....	.....	.....	22 b.	.....
51.		25·3 nf.	.....	25·8 f.	.....	25·3 f.	.....	.....	.....	26·5 vnf.	.....
52.		29·3 •w.	.....	29·1 •	28·1	.....	27·4 c.	.....	28	27·5 • 28·5 c.	.....
53.	ξ		31·3	32·4 f.	.....	30·3 b.	.....	.....	.....	31 vf.	.....
54.				35·7 f.	34·4 b.	.....	33·4 f.	.....	.....	35 nc.	.....
55.	ο	37·3 vf.	38·8 vf.	.....	.....	37·3 vf.	.....	.....	36·5 f.	38·5 c.	.....
56.				39·3 f.	40·3 f.	.....	.....	.....	.....	.....	.....
57.		.....	.....	43·6 c.	.....	.....	.....	.....	.....	42 f.	.....
58.		.....	.....	46·2 f.	45 b.	.....	.....	.....	43 f.	45 f.	46 vf.
59.		.....	.....	50·5 c.	50·2 f.	.....	.....	.....	.....	48 f.	.....
60.	34	.....	.....	56·8 f.	58·1 f.	.....	.....	.....	.....	.....	.....
61.		.....	.....	.....	3·4 f.	.....	.....	.....	.....	.....	.....
62.		.....	.....	.....	6·5	.....	.....	.....	.....	.....	.....

The deposit in the tube very dense. These spectra are notable for the indistinctness of the green lines, as compared with the remarkable sharpness of those in blue and violet. The number visible in the H pair also deserves notice. This metal seems to have great illuminating power.

TABLE VII.—Iron.

		Air.		Nitrogen.		Oxygen.		Hydrogen.		Carb. oxide.	
		C.P.	R.	C.P.	R.	C.P.	R.	C.P.	R.	C.P.	R.
1.	32	37·1 nf.	.....	.....	.....	36·8 *	.....	.....	.....	.....	.....
2.	α	38·4 *	.....	38·4 *	.....	.....	.....	.....	.....	38·4 vb.	38·7 vfo.
3.	α′	.....	.....	40 e.	40·3 of.	39·8 n.	.....	39·7 *o.	.....	39·7 vf.	.....
4.		41·3 b.	.....	42·3 e.	42·9 of.	.....	.....	.....	.....	42·7 vf.	43·3 vfo.
5.	β	.....	.....	45·5 e.	.....	44·8 f.	.....	.....	.....	44·9 vf.	.....
6.	β′	48 *	.....	47·5 *	47·5 of.	47·8 *	.....	.....	.....	47·9 vb.	47·8 vfo.
7.		.....	50·2 b.	50·1 f.	.....	49·8 e.	49·8 f.	.....	.....	49·4 b.	50·7 *
8.		.....	.....	52·4 f.	51·1 f.	.....	.....	.....	51·7 f.	51·4 f.	51·7 n.
9.		.....	.....	54·4 *	.....	.....	.....	.....	.....	53·5 f.	.....
10.	γ	55 *	.....	57·3 vf.	55·3 e.	.....	.....	.....	.....	55·7 *	55·3 wb.
11.	32	.....	59·7 f.	60·3 vf.	59·3 e.	0·8 e. many seen.	.....	.....	0·7 vn.	58 f.	58·6 b.
12.	33	4·2 * double.	.....	2 nb. 3·3 *	.....	.....	.....	4·7	.....	2·6 b. 5 b.	.....
13.		.....	.....	.....	6 *	5·8 nc.	.....	.....	6·2 bw.	6 b.	6 b.
14.		.....	7·7	8·7 vb.	7 n	.....	.....	.....	.....	8 b.	.....
15.		9·5 very many seen here.	.....	10·4 b.	.....	.....	.....	.....	.....	10 b.	.....
16.		.....	11·7	10·7 n. 11·4 b.	11·4 f.	11·8	.....	.....	11·7 nc.	12 b.	10·7 nb.
17.		14 vb.	.....	14 f.	13·4 n.	.....	.....	.....	.....	... b.	13·7 nb.
18.		15 vb.	.....	15·4 f.	15·4 n.	15·8 e.	14·8 w².	.....	.....	14·7 b.	15·4 nb.
19.	ζ	17 vb.	16·7	18 f.	17·7 n.	.....	.....	.....	.....	16·7 b.	17·4 nb.
20.		20 vb.	19·2 f.	20 nf.	20 f.	21·8	.....	.....	.....	20	.....
21.		22·4 vb.	.....	.....	.....	22·8 n.	22·8 e.	.....	.....	21·1	23·4
22.		24·8 *w².	24·7 *	24·1 *	23·7 *	25·3 n.	.....	.....	24·2 b.	25·4 *	24·7 *
23.		.....	.....	26·7 vf.	.....	.....	.....	.....	.....	26·1 nb.	26·1 vf.
24.		.....	.....	28·7 vf.	29·4 f.	.....	.....	.....	29·7 vf.	30·1 vb.	29·4 wb.
25.		31·3 f.	30·7 f.	30·8 b. 31·8 nvf.	32·8 vf.	32·3 vn.	.....	32·7 e.	.....	32·8 vb.	32·8 vf.
26.	ε	34 * double.	.....	33·4 * double.	.....	.....	.....	.....	.....	.....	.....
27.		.....	.....	35·5 f.	.....	35·8 vb.	.....	.....	.....	34·8 vn.	35·1 vf.
28.		36·5 e. many.	.....	36·8 f.	37·5 vf. others seen.	.....	.....	.....	36·2 vfn.	36·1 vb.	.....
29.		39 e.	39·7 f.	39·4 f.	.....	38·3 nf.	.....	.....	.....	38·8 vn.	37·5 nf.
30.		40·5 e.	.....	41·1 b.	40·8 nf.	40·8 b.	39·8 nc.	40·7 *w.	.....	41·2 *w².	40·1 vf.
31.		.....	44·7 b.	.....	44·1 *	.....	43·8 b.	.....	43·7 nc.	44·1 f.	43·4 * 44·7 n.
32.		45·5 c. 46·5 c.	.....	45 b. 46·7 b.	.....	.....	.....	.....	.....	.....	.....
33.		.....	.....	48·5 f.	48 vf.	.....	.....	.....	.....	48·7	.....
34.		.....	.....	49·3 f.	.....	.....	.....	.....	.....	.....	.....
35.		.....	.....	51·3 f.	.....	50·3 *	.....	.....	50·7 vfw.	49·1 nb. 51·3 *	49·3 nf. 50·3 nf.
36.	ι	52·4 *	53·7 b.	53·6 f.	53·3 wb.	52·8 nc.	.....	.....	.....	53·3 nb.	52·3 nf.
37.		55 b.	.....	55·6 *	.....	54·3 *	.....	55·2 nc.	.....	55·3 *	.....
38.	κ	56·6 *	.....	56·6 *	.....	seen.	.....	.....	.....	...	.....
39.	λ	57·3 *	.....	57·2 vn.	.....	57·8 *	.....	.....	.....	57 nc.	.....
40.	33a	59·3 *	.....	58·5 *	.....	.....	.....	.....	.....	58·8 *	.....
41.	34	.....	1·2 e.	1·7 b.	1·1 vf.	.....	.....	.....	.....	.....	many.
42.		4·3 c.	.....	3·6 b.	.....	3·8 n.	.....	.....	.....	.....	.....
43.		.....	.....	5·2 b.	5·9 vb.	...	5·9 e.	.....	5·7 e.	.....	6·2 *
44.		.....	8·7 b.	7·5 f.	.....	7·3 n.	.....	.....	.....	8·8 nb.	8·2 vf.
45.		.....	.....	10·1 *	.....	9·8 n.	.....	.....	.....	10·1 nb.	10·1 vf.
46.		12 * many.	.....	11·4 *	.....	12·8 *	.....	.....	.....	12·7 *	12·4 vf.
47.		15·5 b.	.....	14 f.	.....	.....	.....	.....	.....	.....	15·4 nc.
48.		16·8 *	18·7	16·3 f. 18·6 f.	15·4 n. 18 n.	17·3 n.	16·8 wf.	17·9 *w².	17·7 w.	16·7 b. 18·6 *	16·7 nc. 18·6 nc.
		20 vb.	.....	20·9 f.	19·3 n.	18·8 e.	.....	.....	.....	.....	.....
		21·9 vb.	.....	...	.....	21·8 nc.	.....	.....	.....	21·3 b.	22·6 nc.
		23·7 vb.	.....	23·9 f.	.....	24·8 nb.	.....	.....	.....	.....	.....
		26·5 vb.	26·2 f.	26·2 f.	26·5	27·3 nb.	.....	.....	.....	25·8 *	.....
		30·8 *w².	.....	29·8 *	31·4 f.	.....	.....	.....	.....	...	30·4 f.
		32·5 b.	.....	33·1 nc.	.....	.....	.....	.....	.....	.....	.....
		.....	34·7 f.	35·7 b.	34·4 f.	33·8 b.	.....	.....	.....	34·4 c.	33·7 c.
		37 f.	.....	39 f.	39 f.	37·8 n.	.....	.....	.....	37·7 c.	36 f.
		.....	.....	42·3 f.	.....	40·8 f.	.....	.....	.....	41·6 c.	42·3
		.....	.....	44·2 nc.	.....	.....	.....	.....	.....	44·2 f.	.....
		.....	.....	47·5	.....	46·8 f.	.....	.....	.....	47·3	.....
		51·5	.....	52·1	.....	.....	.....	.....	.....	.....	50·2

These are beautiful spectra, the red brilliant, the violet part specially so, but the yellow often feeble. In air and CO, C.P., the green has a very great number of close narrow lines. In CO, R., the bright lines are very brilliant, the others unusually faint. N and CO were taken with Duboscq.

Table VIII.—Cobalt.

		Air.		Nitrogen.		Oxygen.		Hydrogen.		Carb. oxide.	
		C.P.	R.	C.P.	R.	C.P.	R.	C.P.	R.	C.P.	R.
1.											
2.	33 α	39 *	38·4 of.	39·1 *	34·5 ? vf.	39 *	.....	38·4 so.	38·4 ovf.	38 *	.....
3.	α'	41 vn.	.....	41·1 b.	.....	41 nb.	.....	.....	.....	41 vf.	.....
4.		.....	.....	43·3 c.	.....	43 c.	.....	.....	.....	.....	.....
5.		45 f.	.....	.....	.....	45 c.	.....	.....	.....	45 vf.	.....
6.	β	.....	.....	46·5 f.	.....	.....	.....	.....	47·5 of.	47 *	.....
7.	β'	49 *	.....	48·8 *	.....	48·5 *	.....	.....	.....	49 nb.	.....
8.		.....	.....	50·7 vf.	50·7 vf.	.....	.....	.....	.....	.....	.....
9.		.....	51·4 b.	.....	vf.	.....	.....	.....	.....	51·1 c.	51 c.
10.		.....	52·4 b.	52·7 f.	52·7 vf.	.....	52 vf.	.....	.....	.....	.....
11.	γ	54 *	55·7 nc.	55·3 *	55·3 vf.	.....	.....	.....	.....	53·7 c.	.....
12.		.....	.....	.....	56·7 vf.	56 f.	56 vf.	.....	56·3 c.	56 *	56 f.
13.		.....	.....	58 vf.	58 vf.	... f.	.....	58 f.	58 b.	58 nf.	...
14.	32	.....	59·7 b.	60·6 vf.	60 vf.	59 f.	59·5 vf.	.....	59·3 b.	.....	59·5 f.
15.	33	3 vnb.	3 nc.	2·6 nb.	2 vf.	2 f.	.....	.....	2·6 fn.	2 n.	...
16.	3	4·5 *	.....	4 *	.....	... f.	4 vf.	4 vf.	.....	4 b. double.	3·5 f.
17.		.....	6·7 vb.	.....	6 f.	6·5 f.	.....	.....	6·7 b.	6 f.	6 *
18.		.....	.....	.....	7·3 vf.	.....	8 c.	.....	.....	8 f.	7·5 n.
19.	ε	9 b.	.....	9·4 vb.	9·4 vf.	9 vf.	.....	.....	.....	9·5 f.	.....
20.		.....	.....	10·3 b.	.....	10 *	.....	.....	.....	... f.	.....
21.	ε'	11 b.	11·4 vb.	11·4 brn.	.....	.....	.....	one nf. 11·7 nf.	11·7 b.	11 f.	11·5 bn.
22.	ε''	12 b.	.....	12 b.	12 vb.	.....	12 nc.	one nf.	.....	.....	.....
23.		.....	.....	14·7 vf.	.....	.....	.....	.....	14·7 vf.	14 f.	14 vf.
24.		.....	15·1 vf.	.....	.....	15 n.	16 vf.	.....	.....	15 f.	.....
25.	ζ	17 bw².	.....	17·2 w⁴.	.....	17 *	.....	16·7 c.	17·4 vf.	.....	.....
26.		20 f.	20 f.	.....	20·7 f.	20 b.	20·5 vf.	19·4 f.	20 vf.	20 b.	20·5 vf.
27.		22 vn.	.....	.....	.....	22·5 f.	.....	22·4 nc.	.....	22 b.	.....
28.	η	24 *	23·4 *	24·7 *	25·1 wb.	24·5 f.	23·5 *	24·7 vf.	23·7 c.	25 * double vb.	.....
29.		27 f.	26·1 f.	28·1 vf.	.....	.....	.....	.....	25·7 c.	26 nc.	26 nc.
30.		30 vnb.	29·4 f.	.....	30·1 b.	30·5 w³.	29 vf.	28·7 vf.	29·4 c.	29·5 b.	.....
31.	ι	32 *	32·4 c.	32·1 nb.	32·4 b.	.....	.....	.....	.....	.....	.....
32.		.....	34·8 c.	33·4 *	.....	.....	34 vf.	.....	33·1 c.	.....	.....
33.		36	.....	36·8 f.	35·5 c.	37 *	37 vf.	.....	35·5 c.	36 bn.	.....
34.		40·5 nb.	38·1 c.	39·4 f.	.....	39 f.	40·5 nc.	.....	.....	40 cw².	.....
35.		42 c.	41·4 c.	42·1 bw².	41·7 b.	41 b.	.....	41·4 *	41·4 b.	.....	42·5 *
36.		44 b.	43·7 vb.	.....	43·4 b.	.....	.....	.....	43·4 b.	.....	.....
37.		45·5 b.	.....	46	44·7 b.	.....	44 vb.	.....	45·4 f.	46 n.	44·5 n.
38.		.....	.....	47·4	.....	.....	.....	47·4 vf.	.....	.....	.....
39.		.....	.....	49·3 nf.	.....	49 vn.	.....	.....	.....	48 n.	50 c.
40.	κ	51 b.	51·3 b.	.....	51·3 b.	51 *	.....	.....	50·3 c.	50·5 *	one here
41.		53 f.	52·6 n.	52·6 c.	.....	53 nn.	.....	.....	53·3 c.	52 nc.	53·5 c.
42.	λ	54 *	.....	54·7 nb.	54·7 b.	.....	.....	.....	.....	54·5 *	.....
43.	λ'	55 *	55·1 b.	.....	.....	55 *	.....	.....	.....	.....	55 vf.
44.		.....	56·6 b.	56·3 *	55·9 b.	56·5 n.	.....	56·6 vf.	56·9 b.	56·5 n.	.....
45.	λ''	57 *	.....	57·2 *	.....	.....	.....	.....	.....	.....	.....
46.		.....	.....	58·2 n.	.....	.....	.....	.....	.....	58 vb.	.....
47.	33	60·5 c.	.....	59·1 *	.....	59 *	.....	.....	60·7 b.	.....	.....
48.	34 λ	2 c.	1 vf.	2·3 bn.	1 b.	.....	.....	.....	1·7 n.	.....	.....
49.		4 c.	.....	4·6 bn.	.....	.....	.....	.....	3·9 n.	.....	3·5 vf.
50.		.....	6·5 b.	6·2 bn.	.....	6 nb.	6 f.	.....	6·9 bw³.	5 f.	6·5 *
51.		.....	7·5 f.	8·5 f.	8·2 b.	8 nb.	.....	.....	.....	8 f.	.....
52.	μ	9 b.	.....	.....	.....	10 nb.	.....	.....	9·8 f.	10·5 f.	.....
53.	μ'	11 b.	.....	11·1 *	.....	.....	.....	.....	.....	.....	.....
54.	μ''	12 b.	.....	12·7 *	.....	12·5 *	.....	.....	.....	12 *	.....
55.		.....	13·4 nf.	14·7 f.	14 b.	.....	.....	.....	13·4 f.	.....	.....
56.		16 f.	16·7 c.	.....	.....	16 b.	.....	.....	15·7 f.	16 vb.	15·5 c.
57.		18 b.	18·3 c.	17·3 f.	18·6 nb.	18 *	17 vfw³.	.....	18·6 b.	18 vb.	17·5 c.
58.	ν	20·5 f.	20 c.	19·9 f.	20·6 nb.	21 b.	.....	20 ew⁴.	20·3 n.	21 b.	.....
59.		24 f.	23·2 nvf.	22·6 f.	.....	25 c.	.....	.....	.....	25 *	22·5 n.c.
60.		.....	26·8 vb.	26·5 f.	.....	26·5 c.	.....	26·8 vf.	.....	.....	.....
61.		28 *	27·8 c.	.....	27·8 b.	.....	.....	.....	27·5 f.	.....	.....
62.	ξ	.....	30·8 f.	30·1 *	.....	.....	.....	.....	.....	.....	.....
63.		.....	32·1 f.	.....	.....	.....	.....	.....	32·1 c.	.....	.....
64.	ο	34 fw.	34·1 c.	33·7 b.	34 b.	34 c.	.....	35 vf.	33·7 c.	33 vnf.	.....
65.		.....	36·3 vf.	.....	.....	.....	.....	.....	36·6 c.	.....	.....
66.		.....	38·3 vf.	.....	.....	38·5 n.	.....	.....	37·7 c.	37 f.	.....
67.		40 nc.	39·6 vf.	41 vnf.	40·3 f.	41 n.	.....	.....	39·3 c. 40·6 c.	41 f.	42 vf.
68.		43·5 vf.	42·9 vf.	.....	.....	43 n.	.....	43·9 vf.	42·9 vf.	43 nf.	.....
69.		.....	.....	44·6 nc.	44·9 f.	.....	.....	.....	.....	47 vf.	.....
70.		.....	.....	47·5 vn.	.....	46·5 c.	.....	.....	.....	.....	.....
		.....	50·2 f.	.....	50·5 f.	.....	.....	51·5 vf.	50·5 vf.	.....	.....
		.....	.....	54·1	.....	.....	.....	.....	57·4 vf.	.....	.....
		.....	.....	57·1	57·4 vf.	.....	.....	.....	.....	.....	.....
		.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

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The spectrum O, R., has very little light, and much of it is a mere shadow. In H, C.P., the lines are visible only near the negative electrode, except the *. Above they are lost in a grey haze. Exhausting, the *s and haze vanish, and the other lines stand out conspicuous. In H, R., sometimes the tube was filled with conical strata and the lines were faint; at other times it was filled with a uniform flash, and they were bright. In CO, C.P., the sets 17–24 seem to replace the multitude of close narrow lines that fill the green in this gas in most of its spectra; they are as wide as the slit. The two of CO, the C.P. of air and H, and the R. of O were observed with Merz, the others with Duboscq.

TABLE IX.—Lead.

		Air.		Nitrogen.		Oxygen.		Hydrogen.		Carb. oxide.	
		C.P.	R.	C.P.	R.	C.P.	R.	C.P.	R.	C.P.	R.
1.	32	36·5 b.	.....	.....	.....	.....	.....	.....	.....	.....	.....
2.	*	38·5 b.	37·8 of.	39 *	.....	38·3 *	.....	39 *o.	.....	37·5 *	.....
3.	β'	48 f.	49·1 vf.	48 vf.	.....	48·8 *	.....	.....	.....	47·5 b.	.....
4.		.....	.....	.....	.....	.....	.....	.....	.....	49·5 b.	49 fo.
5.		.....	51 b.	.....	51 f.	.....	50·8 vf.	51·4 f.	51 f.	51·5 f.	52 b.
6.	γ	55 *	.....	55 *	.....	.....	.....	.....	.....	54 f. 54·5 vn.	.....
7.		57 c.	.....	.....	.....	.....	57·8 vf.	57·7 c.	.....	56 vbn.	56 f.
8.	39	.....	58·5 fn.	.....	59 f.	.....	.....	60 f.	59·5 n.	59·8 vf.	0 f.
9.	33	.....	0·6 vf.	.....	.....	.....	.....	1 f.	.....	.....	.....
10.		.....	.....	2 nc.	2·5 nf.	.....	2·3 nf.	.....	.....	2·5 bw².	.....
11.	ϑ	4 *	3 fn.	3·5 *	.....	.....	.....	3·3 f.	3·5 n.	.....	3·5 f.
12.		7 *	6·5 b.	.....	6·5 nb.	6·8 nb.	6·8 b.	6·5 *	6 b.	5·5 f.	7 *
13.	ι	8·5 b.	.....	9 vb.	8·5 vf.	.....	.....	8·7 *	.....	ten or twelve here.	.....
14.	ι'	.....	10·5 nb.	10 b.	.....	.....	.....	.....	.....	.....	.....
15.	ι''	.....	.....	12 b.	13 b.	12·8 nb.	.....	11·7 f.	11 c.	.....	11 nb.
16.	ζ	16 *	.....	17·5 bw².	16 f.	16·8 b.	14·8 w.	16 *	.....	17·5 f.	16·5 bw².
17.		.....	20 f.	20 f.	.....	.....	19·8 nf.	19·7 f.	19·5 n.	20·5 c.	21 f.
18.		.....	.....	.....	.....	22·8 nb.	.....	22·7 f.	.....	22·5 c.	.....
19.	*	24 *	24 *	24 * intense.	24 *	24·8 bn.	23·8 b.	.....	24 *	24·5 n*	24·5 * intense.
20.		.....	.....	.....	25 f.	.....	.....	25·4 f.	.....	25·5 *	.....
21.		.....	.....	27·5 f.	28 f.	.....	.....	28·1 f.	.....	.....	.....
22.		.....	.....	30·5 vbn.	.....	.....	29·8 nf.	30·1 fn.	29·5 f.	30·5 b.	30·5 f.
23.		31 b.	.....	.....	.....	.....	.....	31·8 *	32 f.	.....	.....
24.	ρ	33 *	.....	33 *	32·5 vf.	.....	33·8	33·8 nc.	.....	32·5 nb.	34 vf.
25.		36 f.	.....	36·5 fw.	.....	36·8 b.	.....	36·1	35 f.	35·6 b.	36·5 vf.
27.		.....	.....	.....	37·5 f.	38·8 vn.	37·8 nf.	.....	.....	37·8 b.	.....
28.		41 f.	40 n.	40·5 bw².	.....	40·8 bw.	.....	.....	40 f.	40·5 bw².	40 vf.
29.		.....	43 b.	.....	43·5 *	.....	43·8 c.	42 *w². intense.	42·5	.....	43 *
30.		45 *	.....	45 nc.	.....	.....	.....	.....	.....	.....	.....
31.		.....	.....	46 nc.	.....	.....	.....	46 bn.	.....	46 f.	.....
32.		48·5	.....	.....	.....	.....	.....	48·3 bn.	.....	48·5 vn.	.....
33.		.....	.....	51 f.	50	50·8 *	.....	.....	51·5 f.	50·5 b.	.....
34.	ι	52 b.	.....	.....	52	52·3 vn	52·8 f.	.....	.....	52·5 nc.	52·5 fw².
35.		.....	.....	54 f.	54	54·3 *	.....	.....	.....	54·5 *	.....
36.	ιι'	56 * double	.....	55·5 * 56 *	.....	.....	.....	.....	.....	56·5 f.	.....
37.	33ι''	58 *	.....	58 vb.	.....	58·8 *	.....	.....	59·5 f.	58·5 *	.....
38.	34	.....	.....	1·5 nc.	0 b.	.....	.....	0·3 c.	.....	.....	0 fw.
39.	λ	4 w.	.....	4 nc.	.....	.....	.....	3·6 c.	.....	.....	.....
40.		.....	5 b.	5·5 nc.	.....	4·8 fn.	.....	.....	5 b.	.....	.....
41.		.....	.....	.....	6·5 b.	.....	6·8 c.	6·5 f.n	.....	7·5 vnb.	6·5 *
42.		.....	.....	.....	9·5 n.	8·8 n.	.....	.....	.....	9·5 vnb.	.....
43.	μ	.....	.....	10·5 *	.....	10·8 f.	.....	.....	.....	.....	.....
44.	μ'	11·5 bn.	.....	12 *	.....	11·8 b.	.....	.....	.....	12·5 *	.....
45.	μ''	.....	.....	14 f.	14 f.	.....	.....	.....	14·5 f.	14 nf.	14·5 nc.
46.		17	17 f.	16 f.	16 n.	15·8 n.	15·8 fw.	16 *	.....	15·8 nf.	17 nc.
47.		.....		19·5 f.	18 b.	19·3 b.		17·3 n.		.....	19 nc.
48.	ν	20 nb.	.....	.....	20·5 n.	.....	.....	20·9 *w².	.....	21·5 *	.....
50.		.....	.....	22·5 f.	22·5 f.	21·8 n.	.....	.....	.....	.....	.....
51.		.....	.....	26 vf.	27 c.	24·8 bw².	.....	26·5 f.	.....	26·5 vf.	.....
52.	ξ	30 bw.	.....	29 *	.....	.....	.....	29·5 *	.....	.....	.....
53.		.....	.....	32 c.	.....	32·8 nb.	.....	31·8 nf.	.....	33·5 vf.	.....
54.	ο	35 fw.	.....	35 b.	34 c.	36·8 nb.	.....	35·7 vf.	.....	36·5 vf.	.....
55.		.....	.....	40 n.	40 vf.	39·8 vn.	.....	.....	.....	42 vf.	.....
56.		.....	.....	45 vf.		.....	.....	.....	.....	46·5 vf.	.....
57.		50 vf.	.....	51 f.	.....	48·8 n.	.....	.....	.....	.....	.....

Some of these are peculiar. In air, C.P., No. 12 is the brightest of all, ζ is very brilliant, so is No. 46. The H, C.P., is also greatly developed. It was taken at the negative electrode only. Nos. 2, 29, and 48 reach quite across the spectrum; the others more or less, but on an average about one-third of the way from each electrode, being brightest at the negative. The deposit in the tubes was very considerable, but it does not seem to have cut off much of the spectra. To examine the effect of the diameter of tube, I took (with Duboscq) the air R. in a compound tube, of which the wider parts were 0·4 inch bore, and the narrower 0·04 and 1·5 long. The distance between the electrodes was 5 inches. The discharge was pretty bright in the narrow parts, and red, except on the negative wire, where it was blue. They are as follows:—

			Narrow.	Blue negative.	Red positive.
1.	32	α	38·1 f.	.....	.....
2.			49·1 vf.	.....	.....
3.	32		58 vf. many.	58 vf.	58 vf.
4.	33		0·6 vf.	.....	.....
5.			5·3 n.	6 f.	.....
6.			7·3 n.	.....	7 vf.
7.		ε	9·4 vf.	.....	.....
8.			11 b. others.	10·7 c.	10·5 nb.
9.			14 f. some.	.....	.....
10.		ζ	16·4 f.	.....	.....
11.			20 f.	20·7 c.	.....
12.			22·4 w.	23·4 c.	23 f.
13.			25·7 w.	25·7 c.	.....
14.			28·4 nf. one.	29·4 f.	.....
15.			31·4 nf.	32·1 nc.	30·8 vf.
16.			34·4 c.	35·1 vf.	.....
17.			37·5 c.	37·8 f.	37·8 nf.
18.			40·8 nb.	40·8 nc.	.....
19.			44·1 w.	44·1 vf.	44·1 f.
20.			.....	46·7 vf.	.....
21.			50 b.	51·3 c.	49·3 vf.
22.	33		55·3 b.	54·7 f.	54·3 f.
23.	34		0·4 b.	0·1 f.	0·4 f.
24.			7·5 b.	6·9 f.	6·9 f.
25.			13·4 nb.	12·7 vf.	13·4 vf.
26.			18 c.	.....	.....
27.			.....	18·6 f.	18·6 w.
28.			19·3 c.	.....	.....
29.			26·5 b.	25·8 c.	26·5 vf.
30.			33·1 c.		33·4 vf.
31.			39·6 c.	.....	
32.			49·5 vf.	.....	.....
33.			57·8 vf.	.....	.....

The three evidently represent the same system of lines, for those missing in the second and third have been lost by their faintness. Nos. 12, 19 and 46, Table IX., are resolved by Duboscq into pairs. It also shows 17 which were not visible in the other. Nos. 5 and 11 of that again are not found in these: the first of these is almost peculiar to R. spectra; and its not being visible in the narrow tube here seems to argue that condensed discharge cannot show it.

TABLE X.—Zinc.

		Air.		Nitrogen.		Oxygen.		Hydrogen.		Carb. oxide.	
		C.P.	R.	C.P.	R.	C.P.	R.	C.P.	R.	C.P.	R.
1.	32	37·3 f.	.....	.....	.....	.....	.....	.....	.....	.....	38 o.
2.	α	38·7 ∗	.....	38·4 ∗	38·7 ∗	39·4	.....	39 ∗	39·6 ∗o.	.....	.....
3.	α	40·5 vb.	.....	39·7 b.	.....	41·4 n.	41·3 fo.	.....	.....	40 ∗	.....
4.		43 ∗	.....	42·9 f.	42·8 f.	44·4 n.	.....	.....	.....	.....	42·5 vfo.
5.	β	.....	.....	45·9 f.	45·9 vf.	46·4 n.	.....	.....	.....	.....	.....
6.	β′	48·2 bn.	.....	48·1 vb.	.....	.....	.....	.....	.....	48·2 f.	.....
7.		50·3 ∗	.....	50·1 vf.	51·1 vf.	51·4 n.	.....	.....	.....	50·5 f.	.....
8.		52·1 vb.	.....	52·1 f.	.....	.....	52·6 vf.	.....	.....	52 f.	52 vfo.
9.	γ	54·7 ∗	54·8 f.	54·4 ∗	53·7 vf.	54·4 n.	.....	.....	.....	55 vf.	55 fo.
10.		.....	.....	.....	56·3 nc.	.....	.....	56 vf.	.....	57 vb.	.....
11.		.....	.....	.....	58·3 vn.	57·4 vn.	.....	.....	.....	.....	.....
12.	32	60 b.	.....	.....	59·6 vb.	.....	.....	.....	.....	.....	59·5 f.
13.	33	.....	.....	1·6 nb.	2·3 vnc.	.....	.....	.....	.....	.....	.....
14.	δ	3·7 ∗	4·5 f.	3·3 ∗	.....	3·4 n.	3·8 vf.	4·5 f.	4·6 b.	.....	4 nf.
15.		.....	.....	.....	6 b.	7·4	6·8 c.	.....	.....	7 c.	7 c.
16.	ε	9·5 b.	.....	8·3 b.	.....	9·4 b.	.....	9·5 vf.	.....	9 c.	.....
17.	ε′	10·8 b.	.....	10·4 b.	.....	.....	10·8 nc.	.....	.....	.....	.....
18.		.....	.....	11 b.	11·7 ∗	.....	.....	.....	.....	11 f.	11·5 c.
19.	ε″	12·7 b.	13·5 f.	.....	.....	12·4 b.	.....	.....	.....	13 f.	.....
20.		.....	.....	.....	.....	.....	14·8 fw².	.....	.....	15·5 f.	14·5 f.
21.	ζ	18 b.	16·3 f.	17 bw⁴.	17·2 w².	.....	.....	.....	.....	17 f.	16 vf.
22.		.....	.....	.....	.....	20·4 f.	19·8 n.	.....	.....	19 f.	20·5 vf.
23.		.....	.....	.....	23·7 b.	23·4 bn.	23·8 b. brightest.	.....	.....	23 c.	.....
24.	η	34·8 ∗	25·5 ∗	24·4 ∗	25·1 b.	24·4 bn.	.....	25 vf.	.....	25·5 ∗	25 ∗
25.		.....	.....	25·7 nf.	.....	26·4 bn.	.....	.....	.....	.....	.....
26.		.....	.....	27·1 nf.	27·1	.....	.....	.....	.....	27·5 n.	.....
27.		.....	.....	29·1 nf.	29·1	.....	28·8 w.	.....	.....	29 f.	.....
28.		.....	31·1 f.	31·1 vb.	31·1	30·4 f.	.....	.....	.....	.....	30 fw.
29.		32·4 n.	.....	32·1 vn.	.....	.....	.....	.....	.....	.....	.....
30.	θ	33·7 ∗	34·7 f.	33·5 ∗	33·1	34·4 bn.	.....	34 c.	.....	34 ∗	34 nf.
31.		.....	.....	36·1 f.	35·5	.....	35·8 w.	.....	.....	.....	.....
32.		37·8 ∗w².	.....	.....	.....	37·4 vb.	.....	.....	.....	37 nb.	.....
33.		.....	.....	.....	.....	38·4 vb.	.....	38 vf.	.....	.....	38 f.
34.		.....	40 f.	39·1 f.	39·1 f.	39·4 vb.	.....	.....	.....	.....	.....
35.		.....	42 f.	41·7 w.	41·7 ∗	42·4 w².	41·2 b.	42 ∗w⁴.	.....	41·5 ∗w².	42 ∗vb.
36.		44·7 ∗	.....	.....	43·7 b.	.....	43·8 bw.	.....	.....	44·5 vfn.	44 b.
37.		.....	45·8 c.	45·7 b.	45 b.	45·9 b.	.....	.....	45·6 b.	.....	.....
38.		.....	.....	46·4 b.	.....	.....	.....	46 fn.	.....	47 nc.	.....
39.		49 ∗	.....	48·7 nf.	.....	.....	47·8 n. a fine one	.....	.....	49·5 fn.	48 fn.
40.	ι	50·3 ∗	50·5 f.	50·3 vf.	50·3 c.	50·9 vn.	.....	.....	50·6 f.	.....	50·5 f.
41.		.....	.....	52 f.	52·3 c.	.....	.....	52 vf.	.....	52 ∗	.....
42.		53 ∗	.....	53·6 f.	..... c.	53·9 ∗	.....	.....	53·6 vf.	53 c.	.....
43.	κ	55·6 ∗	55 f.	55·9 ∗	55 c.	.....	.....	56 f.	.....	.....	56 f.
44.	κ′	56·8 ∗	.....	57·2 ∗	56·6 c.	57·4 ∗w.	56·8 n.	.....	.....	57 n.	.....
45.	33κ″	59 ∗	.....	58·2	58·5 nf.	59·9 vn.	.....	59 f.	.....	59 b.	.....
46.	34	.....	1 f.	2 b.	1·1 bn.	0·4 ∗	1·8 vfw.	.....	.....	1 f.	1 f.
47.	λ	.....	3·1 c.	3·9 b.	2·8 bn.	.....	.....	4 vfw.	.....	3 f.	.....
48.		5·8 b.	.....	5·9 f.	5·9 nc.	.....	.....	.....	.....	.....	.....
49.		.....	7 f.	.....	7·2 vb.	6·4 f.	6·8 b.	.....	.....	6·5 f.	7 bw. double.
50.		.....	9·1 f.	8·5 f.	8·5 nf.	.....	.....	.....	.....	8·5 f.	.....
51.	μ	11·3 vb.	.....	11·1 ∗	.....	10·4 nb.	.....	11 vf.	.....	11 f.	.....
52.	μ′	.....	.....	12·7 ∗	.....	12·9 nb.	.....	.....	.....	11·5 vf.	.....
53.		.....	.....	.....	13·7 b.	.....	13·8 f.	.....	.....	13 ∗	13 n.
54.	μ″	14·2 b.	15·1 f.	14·4 f.	.....	14·9 b.	a fine one	.....	.....	14 c.	14 vf.
55.		.....	.....	17·7 f.	18·3 b.	18·4 n.	.....	.....	.....	17 b.	16·5 vf.
56.	ν	20 ∗	20 f.	20·3 f.	20·4 b.	20·9 n.	22·8 f.	21 ∗w².	21 c.	19 ∗	20 c.
57.		.....	.....	23·5 f.	23·2 nc.	23·9 n.	23·8 f.	.....	.....	22 b.	.....
58.		.....	.....	.....	24·9 n.	.....	.....	.....	.....	24 f.	24 c.
59.		.....	.....	.....	25·5 vb.	.....	.....	.....	.....	.....	.....
60.		.....	27 f.	26·8 ...	27·9 f.	29·2 bw⁴.	27·8 f.	27 nc.	.....	27 ∗	28 c.
61.	ξ	30 ∗	.....	29·8 vb.	29·5 nc.	.....	.....	.....	.....	29 n	.....
				30·5 b.							.....
62.		.....	.....	.....	32·1 nc.	.....	.....	.....	.....	33 f.	.....
					34·1 vb.						
63.	ο	.....	35 f.	36·7 vn.	35·4 nf.	.....	35·8 f.	.....	.....	35·5 c.	35 f.
64.		.....		.....	36·7 nf.	36·4 c.		.....	.....	.....	
65.		39 f.	.....	.....	38·6 nf.	.....	.....	.....	.....	.....	.....
66.		.....	.....	.....	40·6 nf.	40·9 nf.	.....	.....	.....	43·5 c.	.....
67.		.....	.....	45·2 f.	45·9 nc.	44·4 nf.	.....	44 fw.	.....	.....	.....
68.		.....	.....	.....	49·8 c.	49·4 f.	.....	.....	.....	48	.....
				52·5	56·1 vf.		.....	.....	.....	.....	.....

This is one of the most splendid spectra, especially at the violet end. N, R., is remarkable for its brightness and the number of its lines. CO, R., has the discharge lilac-coloured instead of green, as is generally the case in this gas.

TABLE XI.—Cadmium.

		Air.		Nitrogen.		Oxygen.		Hydrogen.			Carb. oxide.	
		C.P.	R.	C.P.	R.	C.P.	R.	C.P.	R. 2·55.	R. 0·2.	C.P.	R.
1.	32	35·5 c.	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
2.	α	38·5 • double.	.....	39 •	38 f.	38·8 •	.....	38·8 so.	.....	.....	.....	.....
3.	α′	41 double.	.....	41 n.	.....	39·8 f.	.....	.....	.....	.....	40·7 •	.....
4.		.....	.....	.....	.....	44·8 f.	.....	.....	.....	.....	.....	.....
5.	β	48·5 •	.....	48 f.	49 f.	47·8 •	.....	.....	.....	.....	48·7 •	.....
6.		.....	.....	.....	.....	49·8 n.	50·8 b.	.....	.....	50·5 vf.	50·7 b.	.....
7.		.....	52 c.	.....	.....	.....	53·8 fn.	53·3 vf.	.....	.....	.....	52·7 bw².
8.	γ	54·5 •	.....	55 •	.....	56·3 n.	.....	.....	.....	.....	55·2 n.	55·7 vf.
9.	32	59 n.	.....	.....	.....	.....	58·8 fn.	.....	.....	.....	57·7 •	59·7 f.
10.	33	3·5 •	4 fw.	3 vn. 4 •	3 f.	.....	.....	.....	.....	.....	0·2 fn. 3·7 •	3·7 f. .....
11.		.....	7 c.	.....	.....	.....	5·8 vb. 6·8 nb.	.....	.....	6 fw.	6·7 three.	7·7 •
12.	ι	10 b.	.....	9 b.	.....	.....	.....	.....	.....	.....	9·7 four.	.....
13.	ε′	11·5 b.	11 fn.	10·5 b.	.....	11·3 bn.	10·8	.....	.....	.....	.....	.....
14.	ε″	13 b.	13 vfn.	13 b.	12 b.	13·8 fn.	.....	13·8 f.	14·5 vfw.	.....	.....	13·7 nb.
15.		16 •	.....	15 •	.....	16·3 bw.	14·8	17·3 f.	.....	.....	14·7 four.	16·7 w²f.
16.	ζ	17 •	17 f.	17 •	17 bw.	.....	.....	18·8 f.	.....	.....	.....	.....
17.		.....	.....	.....	.....	21·8 double.	b.	.....	.....	.....	20·7 c. 23·7 c.	21·9 f.
18.	α	25·5 •	24 b. 27 f.	24 •	24·5 bw².	24·8 double.	b. 23·8 •	.....	24·5 vfn.	24 b.	25·7 •	24·7 vb.
19.		.....	28·5 c.	.....	29 c.	.....	28·8 fw.	.....	29 vf.	28·5 bn.	28·7 n.	28·7 bn.
20.		30 vbn.	.....	29·5 nb.	.....	30·3 fw.	.....	30·8 bn.	.....	.....	30·7 f.	.....
21.		32 vn.	.....	31 nb.	.....	.....	.....	.....	.....	.....	.....	.....
22.	β	33·5 •	.....	33 •	33 c.	.....	32·8 f.	.....	.....	.....	.....	34·2 vf.
23.		.....	.....	.....	35 c.	36·3 b.	.....	.....	.....	.....	.....	.....
24.		37·5 f.	.....	38 f.	.....	.....	.....	.....	.....	.....	37·2 f.	38·7 f.
25.		.....	.....	.....	39 n.	39·8 w.	39·8 nb.	.....	40 nf.	39·5 f.	.....	.....
26.		41 f.	42 c.	41 bw.	41·5 bn. 43·5 n.	.....	.....	41·8 •w.	.....	41·5 c.	.....	41·7 nc.
27.		45 •	44 bw.	45·5 •	45·5 bn.	.....	43·8 vb.	45·8 nbw.	45 vfn.	44 c.	43·7 fw².	44·7 b.
28.		.....	.....	.....	.....	.....	.....	.....	.....	.....	47·7 n.	.....
29.	δ	51·5 n.	.....	50 f.	50·5	49·8 •	.....	.....	51·5 vfvn.	.....	51·7 •	.....
30.		53 •	53 cw.	53 c.	52	51·8 n.	51·8 vf.	.....	.....	52·5 cn.	53·2 nc.	54·2 fw.
31.	∞	56 • double.	.....	56 •	55	53·8 •	.....	53·8 n.	.....	.....	54·7 • 57·2 nf.	.....
32.	33	59·5 •	.....	58 •	.....	57·8 •	58·8 vf.	.....	.....	.....	59·2 •	.....
33.	34	.....	2 f.	2 bn.	1 f.	.....	.....	.....	.....	.....	.....	1·7 f.
34.	λ	3·5 cw.	.....	3·5 bn.	.....	.....	.....	.....	.....	.....	.....	.....
35.		.....	.....	4·5 bn.	.....	4·8 bn.	.....	.....	.....	.....	.....	.....
36.		.....	7 cw.	.....	7 f.	7·8 bn.	6·8 vb.	.....	.....	.....	.....	6·3 •
37.		.....	.....	.....	.....	8·8 bn.	.....	.....	.....	.....	9·7 vf.	.....
38.	μ	11 vb.	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
39.	μ′	12 b.	.....	11·5 w.	.....	11·8 bw.	.....	.....	.....	.....	.....	.....
40.	μ″	13·5 b.	.....	.....	14·5 f.	.....	.....	13·8 vf.	13·3 vn.	.....	13·7 b.	.....
41.		.....	.....	.....	.....	15·8 n.	.....	16·3 vf.	.....	.....	.....	15·7 f.
42.		.....	18 f.	.....	.....	17·8 c.	.....	.....	.....	.....	17·7 n.	.....
43.	ν	19 vbn.	.....	.....	19·5 f.	19·8 f.	19·3 vf.	19·8 •w.	.....	.....	19·7 c. 21·7 n.	18·7 f. 23·2 f.
44.		.....	.....	.....	.....	.....	.....	.....	.....	.....	26·7 •	26·7 f.
45.		.....	27·5	26 vfn.	27 f.	25·8 bw².	.....	.....	.....	.....	.....	.....
46.	ξ	29·5 •	.....	30 •	.....	.....	.....	.....	.....	.....	.....	.....
47.		.....	34 f.	33·5 vf.	34 vf.	32·8 nc.	.....	.....	.....	34·5 vfw.	34·7 f.	33·7 f.
48.	ο	35 fw.	.....	36 c.	.....	.....	.....	.....	.....	.....	.....	.....
49.		.....	.....	.....	.....	37·8 f.	.....	.....	.....	.....	38·7 vf.	.....
50.		.....	.....	.....	41 f.	41·8 f.	40·8 vf.	.....	.....	.....	.....	.....
51.		46 f.	.....	.....	.....	45·8 c.	.....	.....	.....	.....	44·7 vf.	43·7 vf.
52.		50·5 vf.	.....	.....	.....	.....	.....	.....	.....	.....	47·7 vf.	45·7 vf.
53.		53·5 vf.	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

I have given here the H transition spectrum. The lines are scarcely visible; they are all found in the other two H. These spectra are exceedingly beautiful, but troublesome in tubes of such small diameter from the dense and opake deposits.

TABLE XII.—Bismuth.

		Air.		Nitrogen.			Oxygen.		Hydrogen.		Carb. oxide.	
		C.P.	R.	C.P.	Ditto—end.	R.	C.P.	R.	C.P.	R.	C.P.	R.
1.	33	39·7 fo.	.....	.....	.....	33·5	.....	.....	.....	.....	.....	.....
2.		39·7 *	.....	39·5 c.	.....	.....	39 *	.....	.....	.....	39·2 *	.....
3.		41·7 b.	.....	40·5	.....	.....	42 f.	.....	40·9 so.	.....	.....	.....
				42·5 f.								
4.	β	.....	.....	46 f.	.....	.....	45 f.	.....	.....	.....	.....	.....
5.	β′	48·7 b. double.	.....	49 c.	.....	.....	49 *	.....	.....	48·9 vf.	47·5 *	.....
6.		.....	.....	51 f.	.....	50·5 vn.	50 f.	.....	.....	.....	49·5 b.	.....
7.		52·2 bn.	52·5 f.	53 f.	.....	first of many.		.....	.....	.....	.....	52·5 f.
8.	γ	55·2 *	no other red.	55 *	.....	.....	.....	.....	56·4 vf.	.....	55·5 vn. 56·5 *	56 f. vn.
9.	32	58·2 c. 58·7 n.	.....	many close here.	.....	60·5 vn.	.....	.....	.....	.....	59 f.	59·5 f. vn.
10.	33	2·2 vbn.	1·5 f.	2 nf.	.....	.....	.....	.....	.....	.....	2·5	.....
11.	δ	3·7 *	.....	4 *	.....	.....	.....	4 fo.	.....	.....	3·5	4·5 vn.c.
12.		6·7 f.	.....	7 vf.	.....	5·5 b.	7 b.	8 f.	6·9 vfn.	.....	5·5 vn.	7·5 *
13.		9·7 b.	9·5 f.	8·5	.....	9·5 f.	.....	.....	.....	9·4 bw.	four here.	9·5 nc.
14.	ε	.....	.....	10 c.	.....	.....	10 vf.	.....	.....	.....	.....	.....
15.	ε′	10·7 b.	.....	11 c.	.....	11·5 vf.	.....	.....	.....	11·4 n.	.....	11·5 vf.
16.	ζ′	13·2 b.	.....	12 c.	.....	.....	13 fw.	12 vf.	.....	.....	12 vn.	.....
17.		14·7 f.	.....	15 nf.	.....	.....	.....	.....	.....	15·4 fn.	four here.	15 f.
18.	ζ	15·7 f.	.....	17 nf.	.....	16·5 f.	17 w.	17 vf.	.....	.....	.....	.....
19.		19·7 vb.	18·5	18 nf.	.....	.....	.....	.....	.....	.....	18·5 vn.	.....
20.		22·7 *	.....	23 vb.	20 b.	.....	21 f.	22 vf.	.....	20·4 vf.	20·5 c.	20·5 f.
21.		24·2 f.	24·5 bw.	.....	23 *	.....	.....	.....	.....	24·4 *	24·5 nb.	24·5 *
22.		25·7 *	.....	.....	25 vn. vb. 26 vb.	.....	25	25 *	.....	.....	25·5 *	.....
23.		27·2 *	.....	27 vf.	27 vb.	.....	.....	27 n.	.....	.....	26·5 nb.	26 vnb.
24.		30·2 bn.	.....	30 nb.	29 vb.	29·5 vb.	.....	30 vf.	29·4 vfn.	.....	.....	.....
25.		32·7 c.	31·5 c.	.....	31 vb.	30·5 vb.	.....	.....	.....	.....	30·5 bn.	30 vf.
26.		33·7 *	.....	33 *	33·5 *	.....	.....	.....	.....	.....	33·2 b.	.....
27.		.....	36·5 fn.	36·5 f.	.....	.....	36·5 vb.	35·5 vf.	36·4 vf.	.....	35 n.	35·5 vf.
28.		37·7 f.	.....	.....	37·5	37·5 c.	38 n.	38 vf.	.....	.....	36·5 nb.	.....
29.		40·7 f.	39·5 f.	39 nf.	.....	39·5 vn.	39 n.	.....	.....	.....	.....	.....
30.		40·7 f.	.....	40	41 w.	.....	41 f.	41 nc.	.....	.....	.....	41 vf.
31.		.....	44·5 w.	45 c.	45 bw.	43·5 b.	.....	.....	42·4 sw.	42·9 bw.	42·5 bw².	44·5 vb.
32.		45·2 cw.	.....	46 c.	double.	.....	44·5 vf.	45 vb.	.....	.....	46·7 vn.	45·5 f.
33.		47·7 b.	.....	48 f.	48 nvc.	48·5 b.	48 bn.	48 vfn.	.....	.....	.....	.....
34.		49·7 *	49·5 nc.	.....	50 nvc.	.....	.....	.....	.....	.....	49·2 vn.	50·5 f.
35.		51·2 b.	.....	51 f.	52 nvc.	.....	52 *	50·5 vnc.	.....	.....	51 *	52·5 f.
36.		.....	.....	53·5 n.	.....	53·5 b.	53 vbn.	.....	.....	.....	53·5 vn.c.	52·5 f.
37.		.....	55 w.	55 *	.....	.....	55 *	.....	.....	.....	54·5 *	54·5 f.
38.		58·2 * double.	.....	56 *	56 * double.	.....	57 n.	.....	.....	.....	57·6 vn.	.....
39.	33a	58·7 c.	.....	59·5 vb.	58·5 b.	59·5 b.	59 *	.....	58·4 c.	.....	58·5 *	.....
40.	34	1·2 *	0·5 w.	.....	2 b.	2 f.	.....	.....	.....	.....	.....	2 vf.
41.		.....	.....	3 n.			.....	.....	.....	.....	.....	.....
42.	λ	4	.....	4 n.	4 f.		.....	.....	.....	.....	.....	.....
43.		.....	.....	5·5 n.	5·5 vf.	6·5 b.	5 cn.	.....	.....	6·4 c.	7·5 nb.	6·5 vb.
44.		8·7 vf.	8·5 w.	.....	.....	.....	8 cn.	8 fw.	.....	.....	9 nb.	.....
45.		.....	.....	.....	.....	.....	9·5 cn.	.....	.....	.....	10·5 nb.	.....
46.	μ	10·7	.....	11	10 f.	.....	.....	.....	.....	.....	11 nb.	.....
47.	μ′	12·2	.....	12	11 f.	12·5 bn.	.....	.....	.....	.....	13·5 *	.....
48.	μ″	13·7	13·5 w.	14	seen. vf.	.....	.....	.....	.....	16·4 vf.	17·7 f.	17
49.		.....	.....	16 f.	.....	.....	16·5 bn.	.....	.....	.....	19·2 c.	18·5
50.		.....	18·5 w.	19 vn. c.	19 fw.	18·5 b.	18 b.	.....	.....	.....	22 f.	20·5
51.	ν	20·2 b.	.....	.....	.....	.....	21 f.	.....	22·4 sw.	.....	.....	23·5 c.
52.		23·7 *	.....	.....	23 nc.	.....	.....	.....	.....	.....	26·8 *	
53.		.....	25·5 w.	25 vf.	27 nb.	25·5 b.	26 b.	.....	.....	.....	.....	.....
54.		28·2 vb. 29·7 vf.	.....	29·5 b.	29 nc.	.....	29·1 wb. 30 vb.	.....	29·4 c.	.....	.....	.....
55.	ξ	.....	32·5 vf.	33·5	34·5 f.	33 vf.	34·5 bn.	.....	.....	.....	34·2 f.	.....
56.		37·7 vfw.	.....	36 f.	.....	.....	.....	.....	.....	.....	38·2 f.	.....
57.		.....	.....	.....	.....	.....	.....	.....	.....	.....	42 f.	.....
58.		.....	.....	.....	.....	.....	.....	.....	.....	.....	46·5 f.	.....
59.		48·2 vf.	.....	.....	.....	.....	.....	.....	.....	.....	48·1 f.	.....

I have given N, C.P., at the negative boundary in part. It seemed identical with the central one till No. 20; so I did not take that part. In the green the lustre of the lines marked b. or vb. is fully that of δ, and they would be marked * if they were as wide as the slit. In the indigo and violet this spectrum has little, if any, superiority of brightness. In air, C.P., No. 20 is the brightest of the whole, and the companion of γ is developed into first-rate brightness. In air, R., there is no red but the single line No. 7.

TABLE XIII.—Tin.

		Air.			Nitrogen.		Oxygen.		Hydrogen.		Carb. oxide.	
		C.P.	R. 2·18.	R. 0·2.	C.P.	R.	C.P.	R.	C.P.	R.	C.P.	R.
1.	32	.....	.....	.....	.....	34 vfo.	.....	.....	.....	.....	.....	.....
2.	32 α	38 * double.	.....	.....	38·5 * double.	39 fo.	39·5 *	.....	37·5 so.	.....	39 b.	.....
3.	32 α′	41·5 *	.....	.....	.....	.....	41·5 n.	.....	.....	.....	.....	.....
4.	32 β	.....	.....	.....	.....	45 vf.	44 f.	.....	.....	.....	.....	.....
5.	32 β′	48 b.	.....	.....	48 b.	47·5 f.	47·5 vf.	.....	.....	.....	48	49 vf.
6.		.....	.....	51·5 c.	.....	51 f.	50 *	51 f.	.....	.....	51	52 c.
							51 bn.					
7.	γ	54 *	53	.....	53 *	.....	54 f.	.....	53·5 n.	.....	.....	.....
8.		.....	.....	.....	.....	55 f.	.....	55 f.	.....	56 fw.	55·5 f.	55 f.
9.	32	58 b.	.....	.....	.....	59 f.	.....	.....	.....	.....	57·5 c.	.....
10.	33	1·5 vbn.	1	.....	1 n.	.....	0 f.	0 f.	1	.....	.....	0 f.
11.	δ	3 *	.....	2·5 b.	3 *	.....	4 f.	4 f.	.....	.....	.....	.....
12.		6 b.	.....	.....	.....	5 c.	.....	.....	7	.....	7 n.	7 *
13.		7·5 b.	.....	.....	8 b.	.....	7·5 f.	8 *	.....	.....	many	8 *
14.	ε	9 b.	.....	.....	9·5 c.	.....	.....	9 n.	.....	.....	here.	.....
15.	ζ′	10 c.	.....	10 c.	10	10 nb.	10 f.	.....	.....	10 b.	.....	.....
16.	ζ	11·5 c.	.....	.....	11	two	.....	.....	.....	.....	.....	12 cn.
17.		.....	.....	14 c.	.....	.....	13 c.	13 cn.	.....	.....	.....	.....
18.	ζ	16 b.	.....	16 c.	16	15 nb.	15·5 n.	.....	15 fw.	.....	.....	16·5 triple.
19.		.....	18·5	.....	.....	.....	18 n.	17 f.	.....	.....	.....	.....
20.		21 n.	.....	.....	.....	.....	21 n.	21 f.	.....	.....	21·5 n.	21 no.
21.	η	23 *	.....	23 w.	23 *	24 b.	24 bn.	24·5 *	22·5 bn.	23·5 vf.	23 c.	24 *
22.		26·5 n. one here.	26·5	.....	25 vf. 27 f.	24·5 n.	26 b.	26 n.	.....	.....	26 *	25 n.
23.		.....	.....	.....	28 bn.	29	.....	29 f.	.....	.....	.....	.....
24.		30·5 vn.	.....	30·5 f.	faint.	31 nf.	31·5 f.	.....	31 b.	.....	31 c.	31 vf.
25.	θ	33 *	32 vfvn.	.....	32 *	34 nf.	.....	.....	.....	.....	33·5 b.	.....
26.		36 f.	.....	.....	35·5	.....	.....	35	.....	.....	.....	36 nf.
27.		38 nf.	.....	38 cn.	37·5 vf.	38 c.	37 bn. 38 cn.	.....	..... one n.	37 vf.	37 c.	.....
28.		.....	40 vf.	.....	39·5 f.	.....	39 vf.	.....	39 * one n.	.....	.....	.....
29.		41 b.	.....	.....	42·5 f.	.....	42	40·5 nc.	.....	.....	.....	41 f.
30.		43·5 c.	.....	44 n.	44 f.	43 b. compound.	.....	44 *	.....	.....	44 b.	44 *
31.		45·5 c.	44·5 vf.	.....	46 f.	.....	.....	one here.	.....	.....	.....	46
32.		.....	.....	.....	49	49 c.	49 f.	.....	.....	.....	49 *	50 f.
33.		50 b.	50 vf.	50 n.	.....	.....	52 *	52 f.	.....	.....	50·5 n.	52 f.
34.		53 c.	52 vf.	53 w.	.....	54 c.	54 n.	.....	53·5 f.	.....	53·5 *	.....
35.	αα′	55 * double.	56 vf.	.....	55 *	56	56 *	.....	.....	.....	55.5 n.	55 f.
36.	33 α′	58 * double.	.....	.....	57 b. double.	.....	58 n.	.....	57·5 f.	.....	57·5 *	.....
37.	34	.....	.....	0·5 cn.	.....	59·5	0 *	1 f.	.....	.....	.....	.....
38.		.....	2 vfw.	.....	2	.....	.....	.....	.....	.....	1 n.	.....
39.	λ	4	.....	.....	3	.....	.....	.....	.....	.....	3·5 n.	.....
40.		.....	.....	.....	5	5 triple.	.....	.....	.....	.....	4·5 n.	.....
41.		.....	.....	8 c.	.....	.....	6 cn.	7 *	.....	.....	7·5 b.	6 b.
42.	μ	10 b.	.....	.....	9·5 b.	.....	9 cn.	.....	.....	.....	9·5 b.	.....
43.	μ′	11 c.	.....	.....	11·5 b.	.....	10·5 cn.	11	.....	.....	11·5 b.	.....
44.	μ″	13 c.	10 f. many n.	13 f.	.....	12·5 double.	13 b.	.....	.....	.....	12·5 b.	.....
45.		17 vfn.	.....	.....	15 f.	.....	17 f.	15·5	.....	.....	16·5 c.	15·5
46.	ν	19 c.	19 f.	19 bw.	18 f.	18	20 c.	20·5 f.	19·6 sw.	.....	18·5 b.	18
47.		.....	.....	.....	22 f.	.....	22 f.	.....	.....	21 vf.	21·5 c.	22
48.		24·5 vfn.	.....	.....	.....	.....	.....	.....	.....	.....	24·5 f.	.....
49.		.....	27 sw.	27 sw.	.....	.....	27 *	.....	.....	.....	26·5 *	26 f.
50.		28·5 sw.	29 f. double.	.....	29 vb.	.....	.....	.....	.....	.....	29·5 f.	.....
51.	ξ	33·5 vf.	.....	34 vf.	33 f.	32	31·5 f.	.....	.....	.....	33·5 f.	.....
52.	ο	.....	.....	.....	35·5 f.	.....	35 bn.	.....	.....	.....	35·5 f.	36 fw[10].
53.		.....	.....	.....	.....	39 f.	38·5 cn.	.....	.....	.....	39·5 f.	.....
54.		.....	.....	.....	43·8 f.	.....	43 cn.	.....	.....	.....	42·5 f.	.....
55.		.....	.....	.....	.....	.....	45	.....	.....	.....	45·5 f.	.....
56.		47 vf.	.....	.....	.....	.....	48 b.	.....	.....	.....	.....	.....

I have given the transition spectrum for air. In it No. 7 is the beginning of light. No. 10 is the beginning of a band almost entirely dark, which occupies the place of δ. Another dark interval at No. 19 seems to replace the bright group ζ, and a third at No. 22 stands for η. No. 25, which, though very faint, is the brightest among them, is the residue of θ. The lines at the violet end are relatively less faded, but are all very obscure.

TABLE XIV.—Antimony.

		Air.		Nitrogen.		Oxygen.		Hydrogen.		Carb. oxide.	
		C.P.	R.	C.P.	R.	C.P.	R.	C.P.	R.	C.P.	R.
1.	32 α	38 f.	.....	39 *	39·3 vfo.	38·8 so.	39·3 o.	39·4 so.	.....	38·7 *	.....
2.	α	41 c.	.....	41 vnf.	.....	.....	.....	.....	41·4 c.	.....	.....
3.	β	45 f. double.	.....	.....	.....	.....	.....	.....	.....	47·7 *	.....
4.	β	49 *	.....	49 nf.	.....	48·3 *	.....	.....	.....	49·7 b.	.....
5.		50 c.	.....	.....	.....	50·3 n.	51·3 f.	.....	.....	.....	.....
6.		53 b.	52·2	.....	52·5	.....	.....	.....	.....	.....	52·2 *
7.	γ	55 *	.....	55 *	55·5 f.	54·8 bn.	.....	.....	.....	54·7 *	55·7 f.
		56 *		.....	60 c.	.....	.....	.....	.....	55·7 *	
8.	32	59 fw.	59·2 n.	.....	.....	.....	.....	60·4 f.	59·4	.....	58·7 c.
9.	33	.....	.....	3 vbn.	.....	2·8 n.	1·8 vn.	.....	.....	2·7 vnc.	.....
10.	δ	3·5 *	4·2	4 *	4 f.	.....	.....	3·9 n.	.....	3·2 *	3·2 f.
11.		5 b.	7·2 b.	.....	7·5	.....	6·8 *	7·4 n.	7·4 c.	7·2 many.	7·2 *
		7 bn.	double.							8·7 many.	8·7 vf.
12.	ε	8 n.	.....	9 b.	.....	8·8 f.	.....	.....	.....		
13.	ζ	10 nf.	.....	10·5 b.	.....	.....	.....	.....	.....	.....	.....
14.	ζ'	11 c.	12·2	12 b.	.....	11·8 nb.	.....	.....	12·4	.....	.....
15.		13·5 b.	.....	13 b.	13 b.	13·8 n.	.....	.....	.....	13·7	.....
16.	ζ	15·5 b.	.....	.....	16·5 vf.	16·8 *	15·3 w².	.....	.....	17·7	15·7 fw.
17.		20 c.	.....	19 bw⁴.	21 vf.	19·8 fn.	19·8 n.	20·9 vn.	.....	20·2 c.	20·7 f.
18.		23 *	.....	23 f.	.....	21·8 n.	22·2 *	.....	.....	22·7 n.	22·7 *
19.	η	24·5 bn.	24·7 bw.	25 *	24 b.	24·8 *	.....	24·5	.....	23·7 nb.	24·2 * many b. and vn.
20.		26 n.	.....	.....	25·5 many n.	.....	.....	.....	25·4	25·7 *w².	.....
21.		30·5 w. some here.	30·2 vf.	.....	30 cw².	29·8 w².	.....	.....	.....	30·7 nb.	28·7 c.
22.	θ	32·5 *	.....	32 vbn.	.....	.....	.....	33 nb.	.....	32·7 *	.....
23.		36 f.	.....	34·5 *	.....	35·8 b.	.....	.....	.....	35·7 nb. double.	34·2 c.
24.		39	.....	37·5 f.	.....	39·8 b.	38·8 vb.	.....	.....	.....	.....
25.		41 c.	41·2 bn.	41 cw².	42 nb.	.....	41·8 b.	40·4 *w.	.....	41·2 bw².	40·7 nb.
26.		44·5 b. one.	43·7 c. double.	45 b.	44·5 bw².	.....	44·3 f.	.....	43·4 bn.	.....	43·7 *
27.		46 b.	.....	46 b.	.....	45·8 f.	.....	.....	.....	45·2 bw². multiple.	.....
28.		48·5 b. double.	.....	.....	.....	.....	48·3 c.	.....	.....	49·2 vnc.	48·7 n.
29.		.....	50·2 f.	51 nf.	50·5 vf.	49·8 *	50·3 n.	.....	.....	50·7 *	49·7 n.
30.	ι	.....	.....	52 nf.	52 vf.	51·8 bn.	52·3 n.	.....	.....	52·7 n.	51·2 n.
31.		54 * double.	.....	53·5 nf.	54 vf.	53·8 *	.....	53·6 vn.	53·4 fw.	54·7 *	53·2 n.
32.	κ'	.....	56·2 f.	56 *	.....	56·8 n.	.....	56·4 vf.	.....	56·2 vnf.	.....
33.	33 *	57·5 bw.	.....	57 *	.....	57·8 *	.....	.....	.....	58·2 *	.....
34.	34	.....	1·2 c.	59 vb.	1 b.	.....	.....	1·4 vf.	.....	0·7 n. three.	.....
35.	λ	3·5 fw. others.	.....	2·5 n. 3·5 n. 5 n.	.....	.....	.....	.....	.....	.....	.....
36.		.....	.....	.....	.....	.....	48 b.	.....	.....	5·7 n.	.....
37.		6·5 vb.	7·2 bw.	.....	7 cw.	6·8 bn.	.....	.....	7·4 bw.	8·7 n.	6·2 b.
38.		11 b.	.....	11 *	.....	9·8 n. others.	.....	.....	.....	10·7 nc.	.....
39.		13 b.	.....	13·5 *	.....	12·8 *	.....	.....	.....	13·7 *	.....
40.		16 b.	.....	16 vn.	16 nc.	16·8 nc.	14·8 c.	.....	.....	16·2 nb.	15·2 nf.
41.		19 c.	.....	18 f.	19 c.	17·8 c.	.....	.....	18·4 f.	19·7 nb.	17·7 nb.
42.		.....	21·7 vf.	20·5 f.	.....	19·8 f.	20·8 bn.	21·4 *w.	.....	21·2 f.	.....
43.		23 n.	.....	24 vf.	23 f.	.....	.....	.....	.....	.....	22·7 c.
44.		26·5 *	26·2 f.	27 f.	27 f.	25·8 *	.....	.....	25·4 f.	26·7 *	25·7 vf.
45.		32 fw.	.....	30 *		.....	.....	.....	.....	30·7 vf.	31·7 f.
46.		.....	.....	33·5 n.	34 vf.	34·3 vn.	.....	.....	.....	35·2 vf.	.....
47.		.....	36·7 cw.	36·5 c.		37·8 vf.	.....	.....	37·4 cw.	38·7 vf.	36·7 vf.
48.		.....	.....	42 vf.	.....	41·8 vf.	40·8	.....	.....	43·7 vf.	41·7 vf.
50.		.....	.....	45 nc.	.....	46·3 f.	.....	.....	.....	47·7 vf.	.....
51.		.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

The deposit on the tubes very troublesome: this is especially the case with metals of this group. In air, exhausting to 0·86 inch, No. 8 is replaced by a narrow *black* band, but reappears on further exhaustion.

Table XV.—Magnesium.

		Air.		Nitrogen.		Oxygen.		Hydrogen.		Carb. oxide.	
		C.P.	R.	C.P.	R.	C.P.	R.	C.P.	R.	C.P.	R.
1.	22 α	39 *	39 vfo.	38·5 * 39·5 nf.	.....	38 f.	37·5 vfo.	39·5 *vb.	38·5 vfo.	38·2 *	.....
2.	α′	41 n.	.....	42 vf.	.....	41 f.	.....	.....	.....	.....	.....
3.		.....	.....	.....	.....	43 f.	.....	.....	.....	.....	.....
4.	β	.....	.....	45 vf.	.....	46 f.	45·3 vfo.	.....	.....	.....	.....
5.	β′	49 b.	.....	47·5 f.	.....	49 vb.	.....	.....	.....	48·2 f.	.....
6.		.....	51 fo.	.....	.....	50·5 vf.	50 nf.	.....	.....	49·7 f.	51·2 nf.
7.		.....	54 fo.	.....	.....	53·5 vf.	.....	.....	52 f.	53·2 vn.	52·7 vfn.
8.	32 γ	55	56 fo.	54 *	.....	55·5 *	.....	.....	.....	55·7 f.	57·2 vnf.
9.	33	.....	0	1 nc.	1 f.	.....	.....	.....	1 vf.	59·2 f.	.....
10.		2 nc.	3	2·5 * double.	3 vf.	2·5 vnc.	2 f.	.....	.....	3·2 c.	2·7 vnf.
11.	3	4 * one follows.	.....	.....	6 n.	3·5 *	.....	4·5 f.	5 vf.	.....	.....
12.		.....	7 vb. one n.	7·5 b.	7 f.	.....	6·5	.....	.....	6·2	6·2 c.
13.	ε	9 b.	.....	9 one. c.	.....	9 b.	9·5 vfn.	.....	.....	many here.	7·2 n.
14.	ε′	10 nb. 11 nf.	.....	10·5 c.	10	10 one. b.	.....	.....	10 vf.	.....	11·2 vn.
15.	ε″	13 nb.	12 bn.	.....	12 vf.	12 b.	12 vfn.	.....	13 c.	.....	.....
16.	ζ	17 w²b.	15 f.	16 w⁴. quadr.	16 vf.	16·7 w⁴. triple.	15 vf.	.....	17 vf.	18·2	15·7 f.
17.		.....	20 f.	.....	19 vf.	.....	18·5 c.	.....	20 vf.	19·2	20·2 f.
18.		.....	.....	.....	.....	23 vn.	.....	.....	.....	22·2 f.	23·2 *
19.	κ	24 *	24 * one in cont.	23	24	24·5 *	24·3 bw².	24 c.	25 vb.	24·2 vn. 25·2 *	23·7 f.
20.		27 vf.	.....	26 f.	.....	28 f.	.....	27 vf.	26·5 f.	27·2	28·2 f.
21.		.....	29·5 vf.	29 n. one.	30 f.	.....	29·5 f.	.....	.....	29·2	...
22.		31 nvb.	.....	31 * doublevrb.	31 f.	31 nc.	31·5 f.	31 vf.	31 f.	.....	...
23.	ι	33 *	.....	.....	34 f.	33 *	33·5 c.	34 nb.	.....	33·7 b.	33·2 f.
24.		36 nb.	34·5 vf.	36·5	.....	37 c.	35·5 c.	.....	.....	35·2 vn.	35·2 f.
25.		39 f.	38 f.	39·5 cw². triple.	38 b.	39 f.	39 c.	38 vf.	39 f.	36·2 bn.	.....
26.		41 w.	.....	.....	.....	41 c. double.	41 nc.	41·7 *w².	.....	40·2 bw⁴.	.....
27.		44 n.	43 * one close.	43	44 b.	.....	.....	.....	43 vn.	.....	42·2 vb.
28.		45 n.	.....	44·5	.....	44·5 c.	45 bw. one.	.....	.....	.....	.....
29.		46 n.	.....	.....	46 vn.	46 c.	.....	46 vf.	45·5 c.	.....	.....
30.		.....	48·5 f.	.....	.....	48 nc.	47 fvn.	47·5 f.	48 f.	48·2 fvn.	.....
31.	ι	51 c.	50 nb.	50 vf.	49 b.	51 *	.....	.....	.....	50·2 vb.	50·7 vf.
32.		.....	.....	.....	.....	.....	.....	52 nc.	52	52·2 nc.	52·2 f.
33.		54 vnc.	.....	54·5 v. double.	54 c.	53·5 nb.	54·5 cw. double.	.....	.....	53·7 *	.....
34.	κ	55·5 *	55 c. double.	.....	.....	55 *	.....	.....	.....	.....	.....
35.	κ′	56·5 *	.....	.....	.....	56 * 57 vn.	.....	56 b. double.	56 double.	56·2 nf.	.....
36.	33κ″	59 b. compound.	.....	57 bw². quadr.	.....	58 *	.....	59 f.	.....	58·2 b.	59·2 f.
37.	34	1 n.	.....	0 1	0·5 c.	1 f.	1 c.	.....	.....	many n. ones here.	.....
38.	λ	3 n.	.....	3	.....	2·5 vn. 3·3 vn.	.....	4 vf.	2 c.	.....	.....
39.		5·5 n.	.....	6 c.	.....	5 vn.	.....	.....	.....	.....	4·2
40.		8 nc.	7·5 double.	.....	7 c.	.....	7 c.	8 vb.	.....	8·2 c. many.	.....
41.		.....	.....	9 *	.....	9 f.	.....	.....	9	.....	.....
42.	μ	10 b.	.....	.....	.....	10·5 c.	.....	.....	.....	.....	.....
43.	μ′	11·5 b.	.....	11 b.	.....	11·5 c.	.....	.....	.....	.....	.....
44.	μ″	13 b.	14 n.	.....	13 c.	13 c.	13·5 c.	14 vn.	.....	13·2	13·7
45.		.....	.....	16 vn.	.....	15·5 c.	.....	.....	15 nb.	15·2 vfn.	.....
46.		16·5	.....	17 fn.	.....	17 nb.	.....	.....	.....	16·2 nb.	17·2 f.
47.	ν	19 nb.	19·5 c. double.	.....	19 c.	19 b.	20 c. mult.	20 *w².	.....	18·7 nb.	20·2 f.
48.		22 vf.	.....	22 vf.	.....	22 nc.	.....	.....	21 double.	21·2 nb.	.....
49.		26·5 c.	27 f.	25 nf.	27 c.	26 nc.	.....	27 nc.	.....	25·7 *	24·7 f.
50.		29·5 vb.	.....	28 b.	.....	29 cw².	27·5 c. mult.	.....	28 b.	.....	.....
51.	ξ	.....	.....	31 f.	.....	.....	.....	.....	.....	.....	32·2 f.
52.		33 c.	.....	34 f.	34 n.	.....	34 c.	.....	34·5	33·2 cvn.	.....
53.	ο	36 f.	35 f.	.....	.....	.....	.....	.....	.....	.....	.....
54.		.....	.....	.....	39 f.	38·5 nf.	40 vf.	.....	.....	37·7 f.	.....
55.		.....	.....	43 f.	.....	42 f.	.....	.....	42 vf.	41·7 vf.	.....
56.		44·5 f.	.....	.....	.....	45 f.	45 vf.	.....	.....	.....	.....
		47 vf.	.....	49·5 f.	.....	47 c.	.....	.....	.....	48·2 vf.	.....

The discharges with this metal were extremely brilliant, so much so in O, that at first I thought the wires were in combustion. The light at the negative electrode was a dazzling green. The deposit was almost as small as that of aluminium, and intercepted very little light. In air, C.P., the comparative dulness of the κ group is peculiar; ρ and ξ are scarcely perceptible.

TABLE XVI.—Tellurium.

		Nitrogen.		Hydrogen.			Nitrogen.		Hydrogen.
		C.P.	R.	C.P.			C.P.	R.	C.P.
1.	32	37·4 f.	.....	.....	35.	°	.....	38·4 *	38·1 f.
2.	α	.....	38·1 b.	39 *	36.		41·4 ww.	41·1 b.	41·4 *
3.	α'	39·7 f.	41 f.	.....	37.		44·7 n.	44·7 *	.....
4.		43 b.	43·3 f.	.....	38.		46·4 b.	.....	.....
5.		44·2 f.	45·5 f.	.....	39.		48·7 f.	.....	.....
6.	β	47·5 c.	.....	.....	40.		.....	50·7 *	51 f.
7.	β'	49·4 f.	48·8 f.	.....	41.		51·6 b.	.....	.....
8.		.....	50·7	.....	42.	ι	53·3 b.	53·6 b.	.....
9.		52·1 f.	52·7	.....	43.		55·3 *	55·3 *	55·9 f.
10.		54 *	54·4	.....	44.	κ	56·6 *	.....	.....
11.	γ	.....	56·3	.....	45.	κ'	.....	.....	.....
12.		57 f.	58	.....	46.	33 κ''	58·5 *	.....	.....
13.	33	59·3 f.	59·6	.....	47.	34	1 c.	0·7 *	.....
14.	33	1·3 b.	1·3 b.	.....	48.		.....	.....	.....
15.		2·6 *	.....	.....	49.	λ	3·6 b.	.....	.....
16.	δ	.....	4 c.	3·6 f.	50.		4·9 c.	.....	.....
17.		.....	6·7 b.	.....	51.		7·5 f.	7·2 *	.....
18.	ϵ	8 *	.....	.....	52.	μ	10·8 *	.....	.....
19.	ϵ'	9·7 fine set.	.....	10·4 f.	53.	μ'	11·4 b.	.....	.....
20.	ϵ''	11 b.	11·7 b.	.....	54.	μ''	13·4 f.	13·4 *	.....
21.		.....	.....	.....	55.		16·7 c.	18 b.	.....
22.		14 f.	.....	.....	56.	ν	19·3 b.	19·9 *	20 ww.
23.	ζ	16·5 b.	17·7 b.	.....	57.		21·3 f.	.....	.....
24.		19 f.	.....	.....	58.		23·9 f.	.....	.....
25.		21·4 f.	.....	.....	59.		26·5 f.	27·2 *	27·2 f.
26.		.....	.....	.....	60.	ξ	29·1 *	30·4 f.	.....
27.	η	24·1 *	24·1 *	.....	61.		33·1 b.	33·7 *	.....
28.		.....	25·4 b.	.....	62.	o	36·3 b.	.....	.....
29.		27·4 f.	.....	.....	63.		39 f.	39·6 b.	.....
30.		30·8 b.	29·8 *	29·4 f.	64.		41·6 f.	.....	.....
31.		32·8 *	32·1 *	.....	65.		46·2 f.	44·6	46·9 f.
32.	θ	.....	.....	33·4 b.			.....	49·2 b.	.....
33.		.....	34·8 b.	.....			52·5 f.	.....	.....
34.		36·8	.....	.....				56·8 f.	.....

TABLE XVII.—Arsenic.

			Nitrogen.		Hydrogen.
			C.P.	R.	C.P.
1.	32		37·7 f.	.....	.....
2.		α	.....	.....	38·7 *
3.		α′	40·7 f.	.....	.....
4.			43·6 f.	42	.....
5.			45·5 f.	.....	.....
6.		β	47·5 b.	.....	46·2 f.
7.		β′	.....	.....	48·2 b.
8.			.....	51·1 f.	50·1 b.
9.			.....	five follow.	50·8 b.
10.			54·7 *	.....	54·7 b.
11.		γ	.....	.....	.....
12.			.....	.....	57·3 b.
13.	32		.....	.....	58 c.
14.	33		.....	1·3 f.	.....
15.			.....	.....	.....
16.		δ	4 *	.....	4·6 *
17.			.....	.....	.....
18.		ε	9 b.	8	9·7 *
19.		ε′	10·7 b. one.	.....	10·7 *
20.		ε″	11·7 b.	11·4 f.	.....
21.			.....	.....	13·7 f.
22.			13·7 f.	14 f.	14·7 f.
23.		ζ	17·4 b.	16·7 f.	17 *
24.			.....	18·7 c.	.....
25.			20·4 f.	.....	19·4 f.
26.			23 f.	22·7 f.	22·1 b.
27.		η	24·7 *	24·1 b.	.....
28.			26·7 b.	25·7 f.	25·4 c.
29.			28·1 b.	29·4 c.	28·1 *
30.			30·1	30·8 f.	30·1 f.
31.			31·4 b.	32·8 c.	32·1 f.
32.		θ	33·2 *	.....	.....
33.			34·8 *	.....	34·8 vb.
34.			37·1 f.	.....	.....
35.			39·8 f.	39·1 b.	.....
36.			42·7 f.	.....	41·7 *w?.
37.			44·7	44·7 b.	.....
38.			46 b.	.....	45·4 f.
39.			.....	47·7	.....
40.			50·3 f.	.....	50 b.
41.			52·3 f.	51·3 b.	52 b.
42.		ι	54 f.	54·7 b.	54 c.
43.			.....	55·9 b.	.....
44.		κ	56·6 *	.....	56·9 *
45.		κ′	.....	.....	.....
46.	33	κ″	59 *	.....	58·5 *
47.	34		.....	1·7 b.	.....
48.			2·3 c.	.....	.....
49.		λ	3·9 c.	.....	2·9 b. double.
50.			5·2 c.	.....	.....
51.			.....	8·2 b.	6·9 b.
52.		μ	.....	.....	9·5 b. double.
53.		μ′	11·1 *	.....	12·4
54.		μ″	13·1 *	14 b.	14
55.			.....	.....	.....
56.		ν	20·6 c.	20·3	22·2 *
57.			.....	.....	.....
58.			.....	.....	.....
59.			27·2 f.	27·8 b.	.....
60.		ξ	29·8 *	.....	29·1 f. 31·1 f.
61.			33·7 f.	34·4 b.	32·7 f. 33·7 f.
62.		ο	37 f.	.....	35 f.
63.			.....	.....	.....
64.			.....	42·3 f.	.....
65.			.....	.....	45·9 f.
			.....	.....	49·5 f.
			.....	51·5 f.	52·1 f.
			.....		55·4 f.

TABLE XVIII.—Potassium.

			Air.	Hydrogen.	
			C.P.	C.P.	R.
1.	32		.....	.....	.....
2.		α	38·4 *	38·7 *	.....
3.		α′	39·7 b.	41·6 f.	.....
4.			42·6	.....	.....
5.			45·5	.....	.....
6.		β	.....	46·2 f.	46·2 f.
7.		β′	48·5 vb.	.....	.....
8.			50·1 vb.	49·8 f.	.....
9.			53·7 f.	.....	51·4 f.
10.			55 *	53·4 f.	54·7
11.		γ	56·7 *	56·3 *	56·7 *
12.			57·3 wvb.	.....	.....
13.	32		.....	.....	59 f.
14.	33		.....	.....	.....
15.			2 c.	2·6 c.	2
16.		δ	4·3 *	.....	4
17.			.....	.....	6·7 b.
18.		ε	9·7 *	.....	7·7 f.
19.		ε′	10·7 b.	.....	.....
20.		ε″	11·4 f.	.....	.....
21.			12 b.	.....	12·7 f.
22.			14 f.	.....	.....
23.		ζ	15·4 n.	16	16 f.
24.			18 n.	.....	.....
25.			19·4 f.	.....	20·7 f.
26.			22·1 f.	.....	.....
27.		η	24·4 *	.....	24·1 b.
28.			.....	26·1 c.	26·1 b.
29.			28·1 b.	.....	.....
30.			31·4 bn.	.....	30·1 f.
31.			32·8 n.	32·8 nb.	32·8 f.
32.		θ	33·4 *	.....	.....
33.			.....	.....	34·8 f.
34.			36·4 c.	37·5 f.	37·8 f.
35.			39·1 c.	.....	.....
36.			41·4 w?b.	42·1 *	40·8 f.
37.			44·1 c.	.....	44·4 b.
38.			44·7 b. 46·7 b.	.....	.....
39.			.....	.....	.....
40.			.....	.....	50·7 n.
41.			52·3	.....	five or six.
42.		ι	54 f.	.....	.....
43.			.....	.....	.....
44.		κ	56·3 *	55·9 n.	.....
45.		κ′	57·2 *	.....	57·2 n.
46.	33	κ″	58·8 *	59·1 c.	.....
47.	34		1·7 f.	.....	1·7 f.
48.			.....	.....	.....
49.		λ	4·2 f.	.....	.....
50.			6·2 f.	6·5	.....
51.			9·1 f.	.....	7·6 c.
52.		μ	10·8	.....	.....
53.		μ′	12·1 n.	.....	.....
54.		μ″	13·5 b.	.....	.....
55.			16·3 f.	16·7 f.	.....
56.		ν	17·3 f. 19·6 b.	20·6 *	20·3 f.
57.			.....	.....	.....
58.			23·2 b.	24·2 f.	23·9 f.
59.			25·2 f. 27·2 c.	.....	.....
60.		ξ	29·8 b.	28·5 n.	28·2 f.
61.			.....	31·8 c.	.....
62.		ο	35 b.	36·7 n.	.....
63.			40 f.	.....	.....
64.			.....	42·3 f.	.....
65.			44·9 f.	.....	.....
			48·9 f.	.....	.....
			51·5 c.	.....	.....
			55·1 f.	54·8	.....

These spectra are in some respects peculiar, those of tellurium most so. In N, C.P., No. 36 is so like the distinctive band of hydrogen that at first I suspected the presence of that gas. The only difference I can find between them is that at the negative electrode it separates into two sharp and bright lines. Still one can scarcely see it, without thinking that there is some close connexion between Te and H.

I have already noticed the extreme brilliancy of its R. spectrum. It is very difficult to work with from its rapid dissipation at the negative electrode, which is so great that a wire 0·01 in diameter disappears in a few minutes; and the deposit is of extreme opacity. In H few lines were seen; for I was obliged to take them at a distance from the electrode, as it became invisible in a few seconds. With arsenic, H, C.P., I was more successful; the centre of the spectrum was a bright cloud, in which only the three bright bands and two or three others were visible. But at the negative boundary I got the largest number of lines, and the brightest that I ever met in H. The arsenic of course soon lined the tube (0·5 inch diameter) with a dark mirror, through which the flash seemed crimson; but an ellipse opposite the plates which form the slit remained quite clear. I suppose the induction of the brass on the tube caused this.

The potassium (air) is of great beauty; the double orange • is of as great intensity as with sodium. No. 7 is an odd-looking olive band. In H, C.P., only the second orange • remains, but it is very bright; the first one is entirely wanting, but reappears in H, R. On exhausting, the second retains its brightness when the rest have vanished.

TABLE XIX.—Sodium.

		Air.		Nitrogen.				Air.		Nitrogen.	
		C.P.	R.	C.P.	R.			C.P.	R.	C.P.	R.
1.	33	.....	.....	36·5 vf.	.....	26.	33	51·5 nb.	51·3 c.	51·6 vf.	51·3 c. double.
2.		.....	.....	37·1 f.	.....						
3.		40·5 •	.....	.....	.....	27.		.....	.....	.....	59 double.
4.		41·5 n.	.....	.....	.....						
5.		49·5 •	.....	48·1 c.	.....	28.		.....	.....	54 f.	.....
6.		.....	.....	.....	53·4 •	29.		56·5 •	55·9 c.	56·6 f.	.....
7.		55·5 n.	56·3 •	55·3 vb.	.....	30.	33	57·5 •	.....	57·2 b.	.....
8.	32	57·5 • vb.	.....	.....	.....	31.	34	0·5 •	1·1 f.	59·1 b.	.....
9.	33	.....	.....	2·6 bn.	.....	32.		.....	.....	2·9 nc.	.....
10.		3·5 n.	3 vf.	4 •	3·3 c.	33.		.....	.....	4·6 nf.	.....
11.		5·5 •	.....	.....	.....	34.		.....	.....	5·2 nc.	.....
12.		8 n.	.....	.....	.....	35.		.....	8·2 vf.	.....	7·8 c.
13.		10 n.	.....	10·7 c.	.....	36.	μ	10·5 c.	.....	11·3 n.	.....
14.		11·5 n.	11·7 c.	12·4 f.	12·4 nb.	37.	μ′	12·5 nf.	.....	one here.	
15.		16·5 w.	.....	17·7	15·7 f.	38.	μ″	13·5 c.	13·4 vf.	13·1 nb. many here.	14·4 c.
16.		.....	21·7 vf.								
17.	•	24·5 •	25·4 f.	25·4 •	26·1 c.	39.		17·5 f.	.....	.....	.....
18.		.....	.....	28·1 vf.	.....	40.		19·5 c.	19·3 vf.	.....	20·3 c.
19.		30·5 bn.	30·4 vf.	31·8 nb.	31·1 f.	41.		28·5 bw.	26·8 c.	.....	27·8 c.
20.	′	33·5 •	33·4 f.	34·1 •	35·5 f.	42.				30·1 bn.	31 nf.
21.		.....	38·1 nf.	37·5 vf.	38·4 c.	43.		.....	.....	33·1 f.	34·7 nf.
22.		.....	.....	40·1 vf.	.....	44.		.....	.....	37·3 f.	
23.		41·5 w.	41·1 nf.	41·4 f.	41·7 c.	45.		.....	.....	39·6 nf.	.....
24.	33	43·5 nc.	43·1	43·4 c.	43·4 b.	46.		.....	.....	45·6 f.	.....
25.		46·5 nc.	.....	47 c.	.....	47.		.....	.....	52·8	.....

The flash of the discharge is white, with a dense yellow atmosphere, to which I think the sodium line No. 8 is due. The Air, R. spectrum is, with the exception of this line, very faint.

TABLE XX.—Graphite.

		Air.	Nitrogen.	Oxygen.	Carb. oxide.				Air.	Nitrogen.	Oxygen.	Carb. oxide.	
		C.P.	C.P.	C.P.	C.P.	R.			C.P.	C.P.	C.P.	C.P.	R.
1.	32	.....	.....	.....	33·9 o.	.....	34.	33	45 *	45·2 } b.	45·4 } b.	.....	.....
2.		.....	36·3 n.	.....	.....	35·8 fo.	35.		.....	46·2 } b.	46·7 } b.	46·7 n.	46·7
3.		39 *	39·8 f.	37·7 c.	38·4 *	38·4 fo.	36.		.....	49·1 f.	49·3 f.	.....	47·9 nc.
4.		.....	41·8	.....	40·3 f.	.....	37.		.....	51·6 } c.	52·6 n.	51·3 *	51·8 nc.
5.		44	.....	43·3 f.	42·9 f.	44·2 fo.	38.		53·5 f.	54·2 } c.	54·3 n.	53·6 nc.	52 b.
6.		.....	45·6 vf.	46·2 f.	45·5 f.	.....	39.		56 *	55·9 *	56·3 *	55·3 *	.....
7.		.....	48·1 *	48·5 *	49·1 f.	.....					double.		
8.		50	.....	.....	50·1 c.	51·1 c.	40.		.....	57·2 *	58·2 fn.	57 c.	57·9
9.		.....	52·5 nf.	52·7 n.	.....	.....	41.	33	58·5 *	59·1 vb.	59·8 *	59·1 *	.....
10.		56 *	54·2 *	55·3 *	56 b.	56 c.	42.	34	..... }	2 ne.	.....	.....	.....
11.	32	.....	.....	.....	58·3 nc.	59·3 c.	43.		3·5	3·8 ne.	.....	.....	.....
12.	33	.....	1·8 vn.	2·3 bvn.	2·8 b.	2·6 c.			com- }				
13.		5 *	4·9 *	4 *	3·6 b.	.....			pound. }				
14.		.....	6·1 f.	6·7 c.	6 nf.	6 n.	44.		.....	5·7 } nc.	.....	.....	6·5
15.		.....	.....	.....	.....	7·3 *	45.	μ	9 }	.....	9·5 vn.	9·1 c.	.....
16.		.....	8·7 vb.	9 vb.	8·3 f.	8·7 } f.	46.	μ'	... }	10·7 nvb.	11·8 vn.	10·1 c.	.....
17.		10 } b.	10·2 b.	10·4 c.	10·4 } f.	10·7 } f.	47.	μ''	13 }	12·4 nb.	13·4 vb.	13·1 *	.....
18.		11 } b.	.....	.....	11·4 } f.	11·7 nc.	48.		.....	seen.	.....	14·7 f.	15 } f.
19.		13 } b.	12 b.	12 c.	12·7 } f.	.....	49.		.....	16·7 f.	16 vf.	17 } b.	17·3 } f.
20.		.....	14·6 vf.	15 }	15 n.	14·7 f.	50.		.....	19·6 f.	18 n.	19 b.	18·6 } f.
21.			16·4 } vf.	... }	.....	.....	51.		.....	.....	19·9 vb.	20·6 n.	.....
22.		18·5	18·1 } vf.	18·4 }	18 f.	.....	52.		.....	22·3 f.	21·9 n.	21·9 } b.	23·2 f.
23.		.....	19·9 vf.	20·7	20 nc.	21 f.	53.		.....	24·3 f.		.....	
24.		.....	22·8 vf.	23·4 b.	22·7 nc.	.....	54.		.....	27 f.	25·8	27·2 *	.....
25.	*	.....	24·6 *	25·1 b.	.....	24·1	55.		.....	30·3 b.	29·8 c.	.....	.....
26.		26 *	.....	26·7 f.	26·1 } *	25·4 } *	56.		.....	33·5 nc.	.....	35 c.	.....
27.		.....	.....	.....	27·1 }	27·1 }	57.		36·5	36·7 nc.	35 b.	36·3 n.	.....
28.		.....	30·2	29·4 vf.	30·8 c.	.....	58.			38·9 vf.	39	38·3 n.	.....
29.		31·5	.....	32·1 nb.	.....	.....					doubtful.		
30.		34 *	33·3 *	34·1 *	33·8 f.	.....	59.		.....	41·9 vf.	42·3 n.	42·3 nc.	.....
31.		.....	36·5 f.	37·5 nb.	36·3 } nb.	.....	60.		.....	44·8 nc.	.....	44·6 n.	.....
32.		.....	39 vf.	38·1 f.	37·5 } n.	.....	61.		.....	.....	45·6 n.	45·6 fn.	.....
				38·8 f.			62.		.....	47·5 vf.	48·9 b.	47·5	.....
33.	33	42	41·4 bw.	41·4 bw.	41·4 b.	.....	63.		.....	51·4 vf.			.....

The electrodes were two of MORDAN'S "leads," and must have been nearly pure; for fragments of them burnt before a gas blowpipe without leaving any sensible residue. The discharge was white except in CO, R. Air, C.P., was taken with Merz, and at an early period.

The next spectra were taken in hopes of obtaining an easy mode of determining the lines due to gases. In the first, electrodes of mercury send the discharge through the vapour of that metal; its lines therefore belong to Hg *exclusively*. Then filling the same apparatus with any gas, the new lines which appear must belong to *it* exclusively; or if (as in the case of platinum, Table II.) the electrode be of a metal on which Hg does not act, *its* lines can be insulated; this, however, assumes that the lines of electrodes and media are independent.

Table XXI.—Mercury.

		Mercury vapour.	Nitrogen.		Hydrogen.	Carb. oxide.	
			C.P.	R.	C.P.	C.P.	R.
1.	3d	.....	36·5 vfo.	.....		.....	.....
2.	α	38·4 fo.	.....	.....	38·5 eo.	38·1 f.	.....
3.	β	49·1 f.	49·1 e.	.....	48·8 b.	48·5 •	.....
4.		50·9 f.	.....	50·7 vf.	50·7 f.	49·8 cn.	.....
5.		.....	.....	52·1 vf.	.....	52·7 f.	52·7 vf.
6.		53·2 f.	.....	.....		53·7 f.	.....
7.		54 f.	.....	.....	54 n.	.....	.....
8.	γ	.....	54·7 b.	55·3 vf.	.....	54·3 b.	56 f.
9.		56·9 f.	57·3 b.	.....		.....	.....
10.		58·6 •	.....	58·6	58 c.	58·6 •	59·6 f.
11.	32	59·7 •	60 •	.....	59·6 •	59·3 •	.....
12.	33	2·6 nc.	0·6 •	.....	.....	3 b.	2 c.
13.	δ	3·3 c.	.....	.....	3·3 •	.....	.....
14.		.....	4·6 b.	.....	.....	4·6 nb.	.....
15.		6 c.	.....	6 vfn.	6 n.	.....	5·6
16.		.....	7·3 f.	.....	7·3 n.	6·7 nb.	.....
17.	ε	8·7 vn.	8·7 fw.	.....	8·7 f.	8·3 nb.	.....
18.		.....	.....	10·7 •	.....	10·7 vn.	10·7 f.
19.	ζ	11·5 •	.....	.....	11·4 •	11·4 •	.....
20.	ζ'	.....	12·7 •	.....	13 b.	12·7 nc.	13·4 b.
21.		14 vf.	14 nc.	14·7 vfw.	.....	.....	.....
22.	ζ	.....	17·4 mf.	.....	16 f.	15·4 f.	17 n.
23.		19·3 vf.	18·7 mf.	19·4 f.	19·4 b.	18·7 f.	.....
24.		.....	20·7 mf.	.....	20·7 f.	.....	21·4 mf.
25.		23·3 vf.	23·4 f.	22·7 several. f.	22·4 b.	22·1 f.	.....
26.	•	24·7 b.	.....	.....	24·7 f.	24·7 b.	.....
27.		26·4 c.	26·1 b.	25·4 f.	26·4 b.	26·1 b.	26·1 vb.
28.		27·9 c.	28·4 f.	28·1 group.	28·1 n.	.....	.....
29.		29·9 f.	.....	.....	29·8 b.	30·1 b.	.....
30.		31·1 f.	33·1 f.	33·1	30·8 b.	.....	31·4 vf.
31.	ι	33·2 f.	33·4 •	.....	32·8 n.	.....	.....
32.		35·8 f.	.....	34·8 vf.	35·5 b.	35·1 nb.	.....
33.		.....	36·8 vf.	.....	.....	37·1 nb.	.....
34.		38·3 c.	.....	38·4 c.	38·5 f.	37·8 nb.	.....
35.		41·1 vb.	40·4 vf.	.....	41·2 ww².	40·8 vf.	41·4 vf.
36.		42·5 b.	.....	43·4 c.	.....	42·1 f.	.....
37.		45·4 fn.	43·4 c. double.	.....	.....	45 c.	.....
38.		47 vf.	.....	.....	.....	47·4 nc.	48·4 •
39.		49·3 fn.	.....	.....	.....	49·3 •	.....
40.		50·3 vn.	50 vf.	50 fn.	.....	50·7 •	.....
41.	κ	52·1 f.	.....	.....	.....	52·6 •	.....
42.		53·1 f.	53 f.	.....	.....	.....	.....
43.	π	55·3 vf.	.....	54·7 w.	55·1 vf.	55·6 •	54·1 f. many.
44.	π'	56·9 f.	56·6 vb. double.	.....	.....	.....	.....
45.	33	.....	58·5 b.	.....	.....	57·9 n.	.....
46.	34 ρ'	0·5 f.	1·7 bn.	1 c.	.....	59·1 c.	.....
47.	λ	3 c.	4·2 bn.	.....	.....	4·2 vf.	.....
48.		6·2 c.	5·9 bn.	6·9 c.	7·5 vf.	.....	.....
49.	ρ	9·5 vf.	10·1 b.	.....	.....	9·5 vf.	8·5 w.
50.	ρ'	12·3 vf.	12·1 b.	.....	.....	10·6 vf.	.....
51.	ρ''	.....	.....	13·1 vfn.	14 vfn.	13·4 nc.	13·7 vf.
52.		15·7 mf.	.....	.....	.....	.....	.....
53.		18·2 •	18 •	17·7 •	18·3 •	18 •	18 nc.
54.	ν	22·9 nc.	.....	20 f.	20·7 ww².	21·6 b.	21·3 f.
55.		25·9 f.	.....	26·8 f.	.....	25·8 b.	.....
56.		28·5 f.	29·1 vb.	.....	.....	.....	.....
57.	ξ	33·5 f.	33·1 nc.	34·1 f.	31·8 vf.	.....	.....
58.		.....	36 c.	.....	.....	.....	.....
59.		42·9 vf.	.....	.....	42·6 vf.	.....	.....
60.		47·4 mf.	.....	.....	.....	.....	.....
61.		50·9 c.	51·5 f.	.....	51·5 vf.	.....	.....

I failed totally in getting the O spectra; for at the very first discharge the mercury was so rapidly oxidated that not a glimmer could pass the thick deposit on the tube. This singular energy is probably due to the presence of ozone in the electrolytic oxygen (though it was passed through a tube filled with silver-leaf). I shall repeat the experiment, passing it through a red-hot tube. This fact may explain the absorption of oxygen in Geissler tubes, which was observed by PLÜCKER; for Hg vapour must be present in them, as they are exhausted by a mercurial air pump. The deposit in CO was black below, grey above: the first was dissolved by nitric acid, the other not; it was probably some form of carbon from the decomposition of the gas; of that, however, there was a large residue present. The spectrum of Hg vapour has a few very brilliant lines, but the rest are narrow and faint on a very dark ground. I had expected by comparing it with Pt, Hg vapour, Table II., to obtain at once the lines of platinum, which I supposed would be *superadded* to those of Hg; but, to my great surprise, that spectrum has *fewer lines* (28, while the other has 48), and only three occur in it which the other wants. A similar deficiency occurs in the gas spectra of Table XXI.: N, C.P., wants 22 mercurial lines; N, R., 25; H, C.P., 20; CO, C.P., 12; and CO, R., 30. These observations, it must be remarked, are strictly comparable; they were all made with the Duboscq prism, nearly at the same time, and with the apparatus in precisely the same condition.

From this may be inferred, either that mercury gives different lines from its vapour, or that the gaseous media have lines which interfere with those of the electrodes so as to destroy each other.

I must reserve for a second communication the complete discussion of these and the other spectra, as it would, I fear, swell this one beyond all reasonable limits.

[P.S. (See page 954.) A more probable explanation of this peculiar form of the spectrum was suggested to me by Mr. STOKES, which is as follows:—

The aperture of the collimator was 1 inch, and its focal length 9·5 inches. The distance of the spark from the slit was probably less than 1·5 inch, say 1·25. Hence if we assume for simplicity that all the light emerging from the collimator entered the object-glass of the observing telescope, which was nearly true, each element of the slit would be capable of being illuminated by rays from a length $l=\frac{1\cdot25}{9\cdot5}\times1=\frac{1}{7\cdot6}$ inch of the spark, provided the spark reached so far, the centre of that line being in a prolongation of the line joining the centre of the object-glass with the element in question. If the length of the spark were very great compared with l, the central parts and those near the electrodes would illuminate widely separated elements of the slit, and the variations of brightness in a vertical direction would nearly correspond with the real variations of brightness of the different parts of the spark—though of course there would be a "ragged edge" above and below, where the spectrum was formed by partial pencils. If, on the other hand, the length of the spark were infinitely small compared with l,

each illuminated element of the slit would receive rays from the whole spark, and the spectrum would be a band of uniform brightness in a vertical direction, and terminating abruptly above and below. In the actual experiment the length of the spark was $\frac{1}{18}$ inch, a quantity comparable with l, being a little less. Hence the spectrum would consist of a central stripe of uniform brightness, corresponding to the small portion of the slit illuminated by the whole of the spark, accompanied above and below by a ragged edge in which the illumination fades away, as more and more of the spark is cut off, till nothing is left but the rays coming from its very extremity. The distance from the central stripe to which the illumination would be perceived to extend would depend on the intrinsic brightness of the part of the spectrum regarded; and, bearing in mind the relative brightness of different parts as laid down by FRAUNHOFER for the solar spectrum, we should get for the visible boundary a curve similar to that represented in the figure. —March 1863.]

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On comparing these Tables, it is seen that the *places* of a very large proportion of these lines are identical, or at least differ only within the limits of observation, although they may be very unlike in brilliancy and magnitude. Such lines must be considered the same; for the essence of a ray is its wave's length, and the difference of intensity is but an accident depending on extrinsic causes. That this comparison may be more easily made, I have given in the following Table the mean places of those whose identity is probable: except in the spectra of iron, copper, and many of carbonic oxide, such are the great majority of what I have observed. For the conspicuous ones, which I have denoted by Greek letters, and which are recognized by peculiar characters, as also for some others which stand in definite relation to them, the means were taken without strict reference to probable errors; for the rest those limits were taken which I have already mentioned. It is possible that in several of the latter class one or two of the outliers may not belong to them; but the general agreement of each is so close as to preclude doubt. I include in the Table none beyond FRAUNHOFER's H, though several were observed, and also omit the very faint red lines which were visible in some spectra outside the bright part*. It gives for each the mean place, the extreme deviations from that mean, the number of C.P. spectra in which it is found, in how many of these it is a *, and the same data for the R. spectra.

* Especially in manganese, A, C.P. This splendid spectrum, which had 74 lines, is not given, as it was not taken in R. or other gases.

Table XXII.

No.	Place.	Diff.	C.P.	a	R.	a	
	° ′						
1.	32 33·80	−1·10 +0·70	3	0	4	0	All the R.s in N.
2.	32 37·43	−0·92 +0·27	17	5	5	0	
3 a.	32 38·68	−1·18 +1·02	76	55	19	2	6 metals show it in all the gases, A has all in N and O.
4 a′.	32 40·62	−0·90 +0·98	55	10	7	0	Often seen, but overpowered by a.
5.	32 42·36	−0·85 +0·54	16	1	7	1	
6.	32 43·34	−0·34 +0·56	14	1	2	0	
7.	32 44·96	−0·96 +0·46	24	0	4	0	O predominates, 5 of N and 9 O wanting in A.
8	32 45·72	−0·72 +0·78	31	0	5	0	
9 β.	32 47·63	−0·55 +0·57	31	11	5	0	In this and the three preceding A has no R.
10 β′.	32 48·78	−0·78 +1·52	60	19	10	0	Rose-red. In C.P., A has all the metals' except β.
11.	32 50·35	−0·33 +0·57	24	2	21	1	10 of N and O wanting in A.
12.	32 51·43	−0·63 +0·57	13	2	43	1	Notable predominance of R.; has few common to C.P.
13.	32 52·56	−0·57 +0·43	22	2	20	4	
14.	32 53·48	−1·48 +0·52	6	0	5	0	Very faint; the companion of γ, always seen with S²C prisms.
15 γ.	32 55·08	−2·08 +1·62	69	46	38	3	Orange; in 16 cases it was resolved in the glass prism.
16.	32 56·21	−0·51 +0·79	20	7	20	1	
17.	32 57·60	−0·70 +0·40	28	1	11	1	No A in N, or N in A.
18.	32 59·02	−0·72 +0·68	24	4	39	2	6 of A not in N or O; 7 of them not in it.
19.	33 0·36	−0·76 +0·54	22	2	26	2	Similar discordance.
20.	33 1·66	−0·66 +0·34	20	0	13	0	Mostly N; 8 of it wanting in A.
21.	33 2·85	−0·60 +0·20	37	5	20	0	Companion of λ, generally νn but νb; always I believe present.
22 λ.	33 3·55	−0·95 +1·45	77	44	35	0	Pure yellow, with 5 metals in all the gases; in A and N with all the metals.
23.	33 6·16	−0·66 +0·54	30	2	34	6	Most frequent in CO.
24.	33 7·09	−0·29 +0·81	22	2	41	9	Many fine lines shown in this region by the S²C prisms.
25.	33 8·37	−0·37 +0·33	25	1	15	3	
26 ε.	33 9·21	−0·91 +0·79	51	5	16	2	Bright green, well characterized.
27 ε′.	33 10·29	−0·49 +0·41	50	2	12	1	Separated from ε by a dark interval.
28.	33 11·23	−0·53 +0·27	32	2	23	2	More frequent in A than N; often too faint to be surely bisected.
29 ε″.	33 12·12	−0·42 +0·68	40	0	30	2	In CO many very fine lines here.
30.	33 13·28	−0·28 +0·52	22	0	14	0	The green ground bright, especially in CO.
31.	33 14·55	−0·85 +0·45	30	1	31	0	
32.	33 15·61	−0·61 +1·09	33	3	29	0	These three are chief in a group which was at first observed as a bright band, and named ζ. The whole ground seems covered with lines, of which 33 is chief.
33.	33 17·17	−0·67 +0·85	52	6	25	0	
34.	33 18·65	−0·65 +0·35	21	1	11	0	
35.	33 19 81	−0·81 +0·29	25	1	23	0	
36.	33 20·93	−0·80 +0·60	31	0	23	0	Most common in CO.

TABLE XXII. (continued).

No.	Place.	Diff.	C.P.	*	R.	*	
37.	33 22·74	−0·74 +1·26	52	8	29	6	
38 *a*.	33 24·52	−1·02 +0·78	63	32	63	25	One of the brightest and most common. With five metals it occurs in every gas.
39.	33 25·82	−0·42 +0·88	45	13	30	3	
40.	33 27·84	−0·84 +0·96	30	1	24	0	
41.	33 29·71	−1·01 +0·79	31	2	43	1	
42.	33 30·93	−0·53 +1·37	65	0	31	1	vb, but n; all the metals in A, all but two in N.
43.	33 32·13	−1·03 +0·67	19	0	11	1	This and the preceding are evidently connected with *δ*.
44 *δ*.	33 33·48	−1·48 +1·52	72	50	42	1	Generally brightest of all, bluish green perfectly characterized.
45.	33 35·59	−0·79 +0·41	27	0	25	0	First of blue, overpowered by glare of *δ*.
46.	33 36·62	−0·52 +0·78	42	1	16	0	Sb is wanting in this and the next.
47.	33 38·00	−0·99 +1·00	37	0	29	1	
48.	33 39·49	−0·49 +1·01	37	3	33	1	
49.	33 41·25	−0·75 +0·85	69	18	48	3	C.P., Al, Pd, Fe have it in all the gases. It is the H blue band.
50.	33 42·86	−0·86 +0·64	11	3	19	10	Well marked; specially bright in R.
51 *ε*.	33 44·49	−0·99 +1·31	55	7	69	0	First of a well-marked pair, universal in A and N, C.P.; frequent in R. with all.
52 *ε'*.	33 46·30	−1·30 +2·30	63	2	20	3	The two extremes very faint; Cd absent in C.P.
53.	33 48·73	−0·73 +1·77	55	9	28	0	Seems connected with the next.
54 *ι*.	33 51·09	−1·09 +1·59	82	28	52	1	With S°C prisms multiple; perhaps the components are sometimes unequally developed.
55.	33 53·38	−1·18 +1·32	66	8	42	0	Generally like a hair, vb, a faint one follows.
56 *κ*.	33 55·33	−1·33 +1·27	77	58	38	1	These are often very intense in C.P.; they are brilliant blue.
57 *κ'*.	33 56·58	−0·58 +1·12	46	42	7	0	
58.	33 57·32	−1·30 +1·48	30	1	2	0	vn; I think always present; the * is with Na.
59 *κ''*.	33 59·08	−2·08 +1·92	81	57	26	0	Beginning of violet.
60.	34 1·12	−1·12 +0·88	28	1	34	1	
61 *λ*.	34 2·72	−0·72 +0·88	38	1	8	0	
62 *λ'*.	34 4·15	−0·65 +0·85	44	1	8	0	These were at first seen as one band before the apparatus was complete. In the C.P. spectra of CO, the ground is covered with fine lines.
63 *λ''*.	34 5·82	−0·92 +0·68	39	1	36	7	
64.	34 7·31	−0·51 +0·49	17	0	29	2	
65.	34 8·46	−0·46 +0·64	34	1	18	0	
66 *μ*.	34 10·31	−1·31 +0·99	67	13	8	0	
67 *μ'*.	34 11·93	−1·03 +0·97	57	14	10	0	A well-marked group in C.P., distinct in almost all the metals and the gases except H. Its parts are all found in R. but in different spectra. The * in *μ''* R. belongs to Te.
68 *μ''*.	34 13·71	−0·91 +1·19	64	10	43	1	
69.	34 15·75	−1·75 +1·05	42	3	22	0	With C.P., Ni, Co; and R., Cu, in all the gases.
70.	34 17·40	−1·20 +0·80	58	9	33	3	
71.	34 19·03	−0·73 +0·87	50	5	35	2	Some of these, especially in H, probably belong to No. 72.
72 *ν*.	34 20·78	−1·28 +2·02	64	13	35	1	In H it is developed into the violet band, whose cloudiness and width explain the range of the measure.

TABLE XXII. (continued).

No.	Place.	Diff.	C.P.	*	R.	*	
73.	34 25·99	−1·19 +1·81	33	1	23	0	None in H, C.P.; four in H, R.
74.	34 25·56	−1·36 +0·94	55	9	22	0	Frequent in N and O.
75.	34 27·45	−0·95 +0·75	36	13	37	2	Only one metal wanting in N, R.
76 ξ.	34 30·09	−0·99 +2·01	62	20	18	0	N, C.P. with all.
77.	34 33·43	−1·63 +1·27	51	1	38	1	The two ** are Al, O; Te, N.
78 ε.	34 35·63	−0·83 +1·67	53	1	19	0	All with Pb, C.P.; the * is Ca, H.
79.	34 39·03	−1·53 +1·27	43	0	19	0	None in H, C.P. These far-violet are ill defined and hard to bisect.
80.	34 41·85	−1·85 +1·85	42	0	28	0	Few in H and A.
81.	34 44·80	−1·85 +1·85	51	0	12	0	With Co, C.P., in all the gases.
82.	34 47·73	−1·22 +1·77	42	0	13	0	Most frequent in CO.
83.	34 51·35	−2·15 +1·45	30	0	14	0	O has only Zn in C.P. and Mg in R.
84.	34 55·81	−2·31 +1·89	15	0	6	0	None in O, C.P.
85.	34 59·34	−2·94 +1·66	10	0	8	0	

Among the most notable of these are,—

No. 3 α. It is one of the three brilliant bands in H, C.P., and is more intense in that gas than in any other. Its mean from 22 of H, C.P., is 32° 38′·52, almost identical with the general mean. It is also extremely intense in other gases, *e. g.* A, with silver and iron; at other times dull or even faint. In H it is generally separated by a dark space from the rest of the spectrum, as if the other red rays were condensed into it. It seems to have a fine line preceding it, which in many cases is separated enough to be bisected. In R. it is of much less importance; its place is that of FRAUNHOFER'S C.

No. 12 is remarkable for its much greater display in R. than in C.P.; the same occurs, though in a less degree, in Nos. 18, 24, and 64.

No. 15 γ. This beautiful band is nearly, but not exactly, in the place of D, and like it is double, though my glass prisms often fail to divide it fairly. With the two prisms of S°C the components are generally equal, but I think further apart than those of D with the same prisms. In K, A, they are seen separate as intense *s; in CO the second is often the brightest. In O it is often dull and sometimes wanting (and the same may be said of the orange and yellow lines generally).

No. 16 coincides with the yellow band of sodium. In the A spectrum of this metal, No. 15 γ is only nb; in N it is a *, but No. 16 is far more brilliant; it retains its brightness during exhaustion and with the spark discharge. It is exactly in the place of D.

Nos. 18 and 19 are intense orange *s in mercury vapour with electrodes of mercury.

No. 22 δ is another beautiful band of common occurrence. In C.P. five metals have it in all the gases; A and N have it with all the metals, though of very unequal brightness; O with 11, H with 12, and CO with 19. It seems to be connected with No. 21,

the ordinary character of which is bn. When examined with the S²C prisms it is triple, the first being very narrow but bright, with a slight tinge of orange, the second and third pure yellow, the second broader than the third, and both sharply defined.

Nos. 26 to 29 form a very conspicuous group. The first, ϵ (which begins the green), is marked by the very obscure interval which separates it from the others; it as well as ϵ'' are double, and the S²C prisms show many fine lines in their neighbourhood. With iron, copper, and in many of the CO spectra, the number of these is very great; it may be that the bright green from this to No. 44 is composed of such lines too close to be resolved; but I think it is continuous.

No. 36 is nearly in the place of E.

No. 38 η is very conspicuous on this bright ground; it is often intensely brilliant, sometimes more so than δ, and it occurs more frequently. No. 37 seems to belong to it; with the S²C prisms, and sometimes with the glass one, it is double of two equal. Its brightness is scarcely developed in O, C.P., very much in N, but quite as much in O, R., as in N, R. CO, R. exceeds them both, though it has only 2 *s in C.P. With platinum, CO, C.P., it is replaced by a bright bluish-green band of singular appearance; this by careful focusing shows eleven or twelve fine lines, of which No. 37 is the first and No. 42 the last. In this spectrum the group ϵ, ϵ'' is also replaced by some twenty-five very fine lines from No. 23 to No. 36. The place of η is identical with the centre of the double line of b.

No. 44 θ, with its companions 42 and 43, is very common, though the latter, 43 especially, are hard to see in the blinding glare of the first, which is often most intense. They are always seen with S²C prisms, which also show θ double (as Duboscq does occasionally). The components are generally, but not always, equal*. Though frequent in R. it is seldom bright. In C.P., N brings it out best; it is wanting in 8 of O, 8 of H, 5 of CO; and of its 50 * O has but 4, H 1, and CO 3; one belongs to mercury in mercury vapour. It ends the green.

No. 49 is remarkable, not only from its being in the place of F, but also from its being (or being in) the characteristic blue band of H, C.P. In the other gases and vapours it is scarcely ever a *, and often faint; here it is of great brightness and great breadth, often 6′ or 7′. It has a cloudy but irresolvable look, and its edges are not sharply defined. Even with 2 S²C prisms I cannot resolve it; and it gives me the impression that it consists of light whose wave-length varies continuously. Its mean by 22H, C.P., is 33° 41′·18, corresponding to a wave length 1798. It is singular that the N, C.P., spectrum of tellurium has a band possessing this peculiar type so decidedly that one who saw it without knowing its origin would undoubtingly assert the presence of H; and my first idea was that this gas must be a component of the metal. If, however,

* In this, as in similar instances, I suspect that an unequal development of the components may disturb the measures. I may at the same time notice another cause of disturbance, the flicker of the light. It might be supposed that the collimator must give an object absolutely fixed, but this is not the case. The discharge being narrower than the slit and at some distance from it, and the want of perfect achromatism in the object-glass, are capable of producing considerable unsteadiness.

the eye be directed to the negative boundary of the spectrum, two brilliant points are seen there not found in the ordinary H band. At the same time they may be due to the grosser metallic vapour which abounds there; for Te volatilizes under the discharge more than any other metal which I have tried. Iron in N, if the pressure be diminished a few inches, shows a similar band, though the other characters of the C.P. spectrum and discharge are unchanged. Zinc in CO, C.P., has one of the same sort 3′ broad.

Nos. 51 and 52 are a well-marked pair; but a much more remarkable group is that from No. 54 ι to No. 59 $\varkappa''$. Of these, 55 and 58 are very narrow, and, though bright, are often overpowered by the splendour of their neighbours; the first has a still fainter follower seen in the S³C prisms, which also show each of the brilliant ones to be compound, ι and $\varkappa$ double, $\varkappa''$ (which begins the violet) to consist of six fine bright lines. In thirty-two cases $\varkappa$ and $\varkappa'$ were observed as one, or as close double. When taken separately, their distance was found 0′·96; and hence the place of $\varkappa$ should be increased, and that of $\varkappa'$ diminished by 0′·14. H is unfavourable to this group, which is most splendid in O and CO, except in Cu, CO, C.P., when it is but a shadow of itself.

The ground is covered with very fine lines from No. 61 to No. 68 in the CO, C.P., spectra of Cu, Pd, Fe, Bi, Sb, and Mg.

No. 72 ν, besides being important in the spectra of other gases, is apparently developed in H, C.P., to the broad violet band, the third of the three brilliant ones of that gas; 22 of H, C.P., give its place 34° 19′·82. It is not nearly so luminous as No. 49 is in H, but is quite as broad and even more undefined. Unlike other violet bands, this is the first to disappear on rarefying the gas. I have occasionally seen fine lines in it, which, however, do not seem to belong to it.

No. 73 is in the place of G, and No. 85 very nearly in that of H.

If the individual spectra be compared with this Table, the result will, I think, throw some light on the questions which I mentioned at the beginning of this paper.

1. As to the *essential* connexion of each line of a spectrum with the chemical nature of some one metal, or some one gaseous medium, I think these observations are against it. For instance, if any line, say No. 22 δ, be found with electrodes of aluminium in all the gases which we have examined, our first inference might be that it is an aluminium line. But when we find the same thing is true of nickel, palladium, antimony, and magnesium, and that all the other metals have it in some of their spectra, we must conclude that it does not belong *exclusively* to any metal; nor can it be considered a gas line. In N it is indeed found with all the twenty-two electrodes; but it also occurs nine times in O, fourteen in H, as well as in the vapours of mercury, phosphorus, and bisulphuret of carbon. There are many similar cases; and though in general the lines of this Table are not seen with all the metals, yet it will be found that, with respect to gases (omitting No. 1, which on account of its bright neighbours is seldom seen), out of the whole eighty-five only Nos. 5, 6, 9, 73, 79, and 85 are wanting* in H, C.P.; only No. 6 in CO, and that of these all but No. 5 are found in the R. spectra, and *none* are wanting in A, N,

* That is, are not visible with my means of observing.

and O. As to metals, the lowest number, 12, occurs in No. 85; but the average is far above this.

These facts may be explained in two ways. We may suppose that the action of the electric discharge on the molecules which transmit it has in itself intermittences which *tend* to produce maxima of light recurring at intervals, and which are effective in doing so when the forces inherent in these molecules are in accordance with them. If that accord be perfect, the development of light will be intense; but if imperfect or wanting, the corresponding light will be feeble or will vanish. Or it may be supposed that our metals and gases are compounds of unknown elements which are separated by the discharge, and exhibit their appropriate lines. This hypothesis is tempting, for if true it would at once lead to analysis of many of our supposed simple substances; and the facts which have been stated respecting the band No. 49 give some countenance to it. I however think the first view of the matter more probable, for reasons which I shall soon state. According to it, the existence of a luminous line merely indicates the presence of *matter* in the circuit; but its intensity depends on the nature of that matter, which may either make it extremely bright or obscure it, even to invisibility. It is generally supposed that the presence of a metal gives brilliant lines, and that those due to a gas or vapour are less bright; but as the two are always simultaneously present it is not easy to separate their influences. A promising plan of effecting this has been proposed by PLÜCKER. Two balls connected by a capillary tube were filled with any gas and then exhausted; the balls were coated with tinfoil, and when they were connected with the terminals of an induction machine *reciprocating* discharges took place, which, though very faint in the globes, were bright enough when condensed in the capillary part to give a spectrum. Here nothing but glass is in contact with the rarefied gas, and therefore he expected to obtain only gas lines. I repeated this experiment, adding a glass stopcock to one of the balls, that I might use the *same* glass with different gases. The spectra observed were the R. of N, O, and H; the first had 13, the second 23, and the last 13, besides several in each too faint to be taken. Of these were—

Common to three.	In N and O.	In O and H.	In O.	In N.	In H.
Nos. 18	Nos. 27	Nos. 49	Nos. 16	Nos. 14	Nos. 5
39	68	75	24	76	13
46			33	84	82
57			36		
61			41		
65			42		
78			44		
			48		
			52		
			54		
			72		

No. 5 is not in any other H spectrum; No. 82 only in Te, A and As, H; No. 16 only in PbO. None of these gas lines is peculiar to that one gas; thus No. 16 is found in N with nine metals and in H with five; this method therefore fails to give the true gas lines. Most of those that are common to two gases will be found in the spectra of sodium, potassium, calcium, and lead, all of which are ingredients of glass; it is hence evident that even reciprocating discharges disintegrate the surface of glass.

A plan of mine seemed more promising. With an apparatus which I have already described, I took the spectrum in mercury vapour with mercury electrodes; then filling the tube with a gas, I took the new spectrum. I tried N, O, H, and CO. O failed from its extraordinary action on the mercury, which in a few seconds blackened the tube, so that not a ray from the flash was visible. I expected that the gas lines would be thus easily obtained, but was disappointed.

Hg Hg	has 48 lines			
Hg, N, C.P.,	has 36 lines		N, C.P.,	has 10 not in Hg Hg
Hg, N, R.,	has 23 lines	Of these	N, R.,	has 4
Hg, H, C.P.,	has 33 lines		H, C.P.,	has 7
Hg, CO, C.P.,	has 41 lines		CO, C.P.,	has 10
Hg, CO, R.,	has 18 lines		CO, R.,	has 8

Of these last Nos. 2, 46, 59, and 78 are found in N only (that is with Hg electrodes, for with other metals they occur in *all* the gases). Nos. 13 and 32 belong to CO, the rest are common to the three gases. It deserves notice that many of the lines of Hg Hg are wanting in the gases, the lowest number being 13 in CO, C.P., the highest (29) in CO, R. This may partly arise from mercury and its vapour having different sets of lines, the latter of which are displaced by those of the gas, fewer in number Were this the sole cause, the same lines would be missing in each gas spectrum; and the difference of the numbers shows that the presence of a gas actually *prevents* the development of some mercurial lines. Corresponding facts occur in other spectra, those of H especially.

The effect of a metal is most perceptible near the negative boundary of a spectrum, where some lines are brilliant for a short distance and then continue with much less brightness. The contrast is so great that, without measurement, one could scarcely believe the line to be the same. That its existence in the faint state is due to that metal which causes its partial splendour, is disproved by its occurring with other metals. In illustration I refer to the spectrum of bismuth (N) at the negative edge as compared to that of the centre (Table XII.), where it is seen that though lines (especially in the green) which are scarcely visible in the latter are intensely bright in the former, and faint single lines are seen as two, yet no decidedly new one appears. This is most remarkable with the volatile metals. Thus As, H, C.P., shows at the negative edge forty-four lines, of which ten are ••s and eleven more are "bright." These retain their lustre for 10′ or 11′, and then (except the three hydrogen bands) can scarcely be traced across.

None of these, however, are peculiar, except that Nos. 11, 17, and 54* appear as double.

That the presence of a new body in the circuit developes oftener than originates lines, is further shown by moistening the electrodes with a solution of some salt; for instance, chloride of barium†. In trying it, platinum electrodes (carefully washed with nitric acid and distilled water) were lapped with *clean* cotton thread to retain the fluid, which, however, soon evaporates by the heat of the discharge. The change of the spectrum is almost startling from the instantaneous and intense development of many lines, and the increased lustre of some which before had been noted as •s. The most conspicuous are—

	°	′
α. Very bright	32	38·1
α'. • very intense		40·0
β'. • dazzling		49·1
γ. Very bright		54·7
No. 16. Orange intense . . .		56·3
No. 17. Very bright		57·7
No. 34. • very intense	33	18·4

Nothing striking till θ, then

No. 47. • brighter than θ . . .		37·4
No. 48. Almost •		39·4
λ. • of exceeding intensity . .	34	2·3
λ'. Very bright		4·6
No. 80. Extremely bright . . .		40·6

All these are found in the platinum air spectrum, though in most cases with a totally different aspect; so that the barium makes no change in the place of the lines, but only in their brightness.

2. That the peculiar character of a line is modified by other circumstances than the chemical nature of the bodies engaged in producing it, appears from the difference between the spectrum at common-pressure, the transition spectrum, and that in rarefied gases, to which I have already referred. The chemical conditions are unchanged; but at first sight nothing is more dissimilar than the three; the first with its numerous bright •s; the second a shadow rather than a spectrum, with a bare suspicion of a few lines; and the R. one much brighter, but with a seeming discrepancy of lines that marks it as peculiar. The R. has, on an average, 0·53 of the C.P. lines; it extends as far in the violet, but is cut off in the red part. There, especially in N, are often found a set of equal bands reaching from No. 11 to No. 19 inclusive; there is also another set, that

* This line is always double with $S^{a}C$ prisms.

† It is desirable to ascertain whether this process gives a spectrum always identical with that given by electrodes of the metal contained in the salt. The difference of aggregation and the presence of water may modify it considerably.

looks like a row of luminous pillars, from No. 53 to No. 77. In general the R. spectra are much fainter than the C.P.; the brilliant No. 3 α, 15 γ, 22 δ, 44 θ, and the $\varkappa$ group are inconspicuous, though often present. On the other hand, some are occasionally brilliant; thus 38 η occurs as * twenty-five times; 23 and 24 have more *s in R. than C.P.; and the R. spectrum, Te, N, is positively splendid with thirteen *s. But I think there is no instance of a line† occurring in any R. which is not found in some C.P., or *vice versâ*. These differences may be attributed to three causes. First, the discharge which at C.P. passes in a flash of, probably, evanescent section, must be very much brighter than when diffused in a tube of 0·2 inch diameter, which it fills completely. This would account for the lines being fainter, but not for the difference of character. In a compound tube of two pieces, 0·5 inch diameter connected by one 0·05 inch, with lead electrodes, A., R., the spectrum in the narrow part had more lines than in either of the wider, as being brighter; but it contained all theirs, and was quite distinct from the C.P. Secondly, it may be thought that the air is less heated, because of the less resistance and the greater heat-capacity of rarefied gas. Were this the principal cause, the R. ought *never* to contain more lines than the corresponding C.P., much less have any as a * which is faint in the other; the transition-spectrum, too, should be more luminous than the R. Thirdly, the mere increased distance of the gas molecules *may* modify the light-vibrations. This is mere guess; but so is much more of our speculation on this mysterious subject, and it may at least point out the road for future research. Experiments at pressures greater than the atmospheric, produced by mechanical force or heat, and with electrodes in various states of aggregation, would probably throw light on the subject. One thing must be remembered: in these R. discharges the light, when viewed in a revolving mirror, has a certain permanence; but in the C.P. it is, so to say, instantaneous.

3. It is generally believed that each of the bodies present in the track of a discharge has its own independent spectrum, coexisting with those of the others and in nowise interfering with them. This is not universally true, as will be seen by comparing the spectra of air, both C.P. and R., with those of its components N and O. Without going through the entire series, but taking the first twenty-five numbers of the Table, and the last, I find that out of

353	lines found in	A., C.P., there are neither in N nor O.	71
156	„	A., R., „ „	62
404	„	N, C.P., there are wanting in A . .	186
226	„	N, R., „ „	124
314	„	O, C.P., there are wanting in N and A.	133
133	„	O, R., „ „	52

Many of those wanting in A are found both in N and O. From these numbers it is

† Of course I mean the lines of this Table, without including in the statement those of special character and peculiar origin.

evident both that the spectrum of air is not formed by the mere superposition of those of N and O, and that certain electrodes can excite lines in a mixture of two gases which are not visible in either of those gases taken separately, or cannot excite them in the mixture, though they can in either or both of the components. This unexpected fact is illustrated by an attempt which I made to obtain the lines of platinum, by comparing its spectrum in mercury vapour with that of mercury. I expected, as I had done in the cases already mentioned of gases with Hg electrodes, that I should get the spectrum of Pt + that of Hg; but the result was otherwise. Hg Hg had forty-eight lines, Pt Hg only twenty-five, so that the presence of Pt instead of Hg as electrodes *put out* twenty-three. It however brought out four new ones, of which No. 15 γ is found with *every solid* metal, Nos. 33, 59 $\varkappa''$, and 76 ξ with most of them. There is here no superposition, but, instead, either an antagonism of platinum and mercury, or the curious fact that the fluid electrodes act differently from the solid. It would be interesting to compare the spectra of tin in these two states.

The case is the same with a chemical compound as with a mixture. On the principle of superposition, the spectrum of CO should be merely the sum of those of C and O. To avoid all uncertainty about metallic lines, I used electrodes of graphite in the two gases. In each case nothing but C and O were present, and I expected to get the same spectrum in both. They were, however, very unlike. Of the lines which they had in common,

No. 3 α	is nc. in	. .	O, but is a • in	. . . .	CO
No. 10 β'	is a • in	.	O, but only c. in	. . . .	CO
No. 15 γ	is a • in	.	O, but only b. in	. . . .	CO
No. 22 δ	is intense • in		O, but only b. in	. . . .	CO
No. 26 ε	is wvb. in	.	O, but one of many very fine in		CO
No. 39	is faint in	.	O, but a • as bright as η in	.	CO

The $\varkappa$ group is not nearly so bright in O as in CO.

Besides these differences, O has ten wanting in CO, among which are No. 38 η, very bright, and No. 44 θ, in all its brilliancy; while CO has eight wanting in O, of which No. 75 is a •; the difference being greater than I have sometimes found with much less chemical agreement.

The only conclusion which such facts permit is, that the spectrum is a simple resultant of all the actions present, some of which may combine to produce an exalted effect, while others may be antagonistic in any degree.

4. As to the manner in which electricity produces the rays of these lines, whether by merely heating the medium, or by some luminiferous action analogous to its heating, nothing is really established. Heat is known to produce some brilliant lines when metallic vapours are introduced into flames; and it is possible that a temperature far above that of our hottest flame might bring out all those which I have enumerated, and the multitude of others which I did not attempt to measure. But is the temperature of the elec-

tric discharge so immensely superior to all others? and are there no means of estimating its real amount? Two of the facts which I have noted respecting these discharges may at least direct attention to this subject. In general the spectra of the simple spark of an induction machine are much fainter than when a jar, however small, is connected with it; and those with a small jar than those with a large. Thus, with silver electrodes in air, the spark gave twenty-three lines, of which δ and θ were "very bright;" a jar of 0·5 foot coating gave also twenty-three, but differently placed, more at the red, fewer at the violet, but seven of them ⁂; the normal one of 1·25 foot gave thirty-one, with nine ⁂; and two large of 8·5 feet gave thirty-six, with ten ⁂ and many others "very bright." In these cases, were one to judge from first appearances, the spark heats air much more than the jar-discharge, for it has much greater power to burn anything which it encounters; but its section is larger, because much of it is *conducted* by the air which surrounds it; and besides, from the diminished resistance, the amount of heat produced *may* be less, as well as less concentrated. We cannot say it *must* be; we know too little of the nature of induction discharge to estimate the effect of changing resistance, for if it be increased it is possible that part of the electricity may be discharged through the coil itself. It must also be kept in mind, that while the jar-discharge is almost instantaneous, the other, at least in part, has a sensible duration. It could, however, be easily decided by experiment whether more heat is evolved in the C.P. or R. discharge.

Secondly. My induction machine, as I have already stated, can be used collaterally; in this case the quantity is double, and should have a fourfold heating power. In fact, its discharge (or rather the air which that discharge heats) fuses a piece of platinum wire, which the consecutive arrangement only reddens. Now, if the lines were produced by mere heat, the spectrum of the former discharge should be far the brightest: it is not so in the red and green; in the violet there is a difference, but I think an unpractised observer would scarcely notice it. I however saw the lines beyond H more easily and further. Unless the temperature is sufficiently raised by a weaker discharge than either of these to bring out all the lines (which seems inconsistent with the effects obtained by enlarging the jar), we might expect here, from the heat theory, a greater change. It is, I think, worth pushing the trial further, and I intend to repeat the experiment with an induction machine of much greater quantity, and at the same time to ascertain if intensity also have any influence.

These observations, on the whole, incline me to refer the origin of the lines to some yet undiscovered relation between matter in general and the transfer of electric action. According to the special properties of the molecules which are present, the brightness of these lines will be modified through a range from great intensity down to a faintness which may elude our most powerful means of observation. If several sorts of molecules be simultaneously present, there may be expected interferences which will produce alternations of brilliancy or obscurity to any extent; and if any of these be chemically united, analogy leads us to expect that such compound molecules will act with an influence of

their own different from that of their elements. In even a simple mixture like air, I have shown that its spectrum, with a given metal, cannot certainly be deduced from those of its parts, and it is probable that this rule may be widely extended.

The bearing of this on electro-spectral analysis is obvious; for if the presence of one substance can be shown in any instance to disguise or transform the spectrum of another, or if the state of density, solution, alloyage, &c. have influence, it becomes necessary to eliminate such effects before we yield implicit confidence to this powerful guide. This implies a wide range of experiment and of cautious study; in fact, a complete system of spectral research through the whole range of our chemical elements *and their compounds*, conducted with strict inductive logic, and with the highest appliances of chemistry and optics. Whatever shall be so effected will be "an everlasting gift" to science, because, taking nothing for granted, it will be a real fact.

XXXVIII. *Experimental Researches on the Transmission of Electric Signals through Submarine Cables.*—Part I. *Laws of Transmission through various lengths of one Cable.* *By* FLEEMING JENKIN, *Esq.* *Communicated by* C. WHEATSTONE, *Esq.*, *F.R.S.*

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IN a paper by Professor W. THOMSON "On the Theory of the Electric Telegraph," communicated to the Royal Society in 1855*, the peculiar circumstances affecting submarine wires were especially analysed, and it is probable that all the laws regulating the transmission of signals could, by further development, be deduced from the mathematical theory there stated, if the necessary constants were known.

It is hoped that some account of an experimental research into the same subject may be found interesting, especially as the experiments not only confirmed the conclusions arrived at by Professor W. THOMSON, but led also to the discovery of several facts of considerable practical importance.

With the view of elucidating the present subject, many experiments have been made on the charge and discharge observable at the near end of a cable; but although this charge is intimately connected with the retardation of signals, the connexion is complicated, and many false deductions have been drawn from the facts observed.

The author preferred to make his experiments on the signal or current actually received at the far end of the wire, the object being to establish a direct relation between the causes operating at one end and the effects observed at the other. Some experiments of this kind have also been made, but the instruments used have been such as could only indicate some one point of the complete phenomenon, such as the presence or absence of a given current, and the conclusions so arrived at vary with the nature of the instrument employed.

The author used an instrument by which he was able to follow the phenomena throughout, observing the nature and magnitude of every change produced in the received current. An attempt was first made to obtain by experiment, from various lengths of cable, and with various battery power, the curve given by Professor THOMSON in the above-named paper, and called by him "the curve representing the gradual rise of the current in the remote instrument when the end operated on is kept permanently in connexion with the battery." This curve will in the present paper be called the arrival-curve.

The effect of continually repeated signals of various kinds was next studied, with various lengths of cable and various arrangements of battery, in order to determine in each case the practicable speed† of signalling.

* *Vide* Proceedings of the Royal Society, May 1855, and Philosophical Magazine, S. 4. vol. xi. p. 146.

† In this paper, where the words "speed of signalling" or "rate of transmission" are used, the author

Certain modifications of the usual signals were by these means discovered which materially increased the rate of legible transmission.

These experiments were all made on one cable, and do not therefore refer to the effects produced by a change of dimensions or materials; they will now be described in detail, and the connexion of the results with the mathematical theory will then be mentioned.

The Red Sea cable only was used in all the experiments; the external diameter of the insulated wire was 0·34 inch; the gutta percha weighed 212 lbs. per knot; the conductor was a copper strand of seven wires, and weighed 180 lbs. per knot. The extreme diameter of the strand was about 0·105 inch, and the ratio of the external to the internal diameter of the gutta percha sheath may be taken as 3·4. The resistance of the conductor per knot was 25×10^7 British absolute units.

The first experiment was made on July 26th, 1859, with 2168 knots disposed in ten coils, each about 26 feet in diameter, and held in a dry iron tank; the cable A C X, the battery B, a Morse key M, a galvanometer G, and the two earth-plates E E were connected as in fig. 1, Plate XLIX.

The effect at the end X produced by connecting the cable at A alternately with the battery and the earth-plate by means of the key was observed on the galvanometer G, being Professor THOMSON'S marine galvanometer.

The suspended magnet m of this galvanometer carried a little mirror n reflecting the image of a flame B on to a scale A about 26 inches off, as shown in fig. 2. The zero of the scale was in the middle, and each division was equal to $\frac{1}{10}$th of an inch. The coil C is shown in section, and the little lens L in its position in front of the mirror. The deviations of the spot of light from the centre measured on the scale were sensibly proportional to the strength of the current causing the deflection, when the deviations did not exceed 200 divisions.

The little magnet was powerfully directed by a fixed external steel magnet N S. The weight of the moveable magnet and mirror was about $1\frac{1}{2}$ grain; the inertia of the moving parts was consequently so small, and the directing force so great, that the variations of a rapidly changing current were accurately represented by the movements of the spot of light along the scale. When the Morse key (fig. 1) was pressed down, the spot of light remained apparently motionless for a short but sensible time, then shot along the scale, moving rapidly at first, but gradually losing speed, until at last it moved very slowly to a maximum deviation, at which it remained quite still: these movements truly showed the gradual change of the received current from nothing to a maximum, a change requiring fifty seconds for its completion. During the latter part of this time the movement of the spot was slow enough to allow the moment at which it passed any given division of the scale to be pretty accurately fixed. Two observers

refers to the speed with which certain changes in the received current called signals can be made to follow each other, and not to the velocity of propagation of the electric current.

were wanted, one noting by the seconds hand of a watch the interval between the sound of the contact made by the Morse key, and the sound of a little blow struck by the other at the moment when the spot passed the given division.

Only one observation could in general be made each time the current entered the cable. The results of the observations are given in Table I.

The maximum current from a battery of 72 Daniell's cells caused a deviation of 130 divisions. The strength of this permanent current depends simply on the electromotive force of the battery and the resistance of the various parts of the circuit, being quite independent of the inductive phenomena.

The first column shows the number of seconds during which the current had been flowing into the cable when the spot had reached the division of the scale entered immediately beneath in the second column. The third column shows the percentage of the maximum deviation, or strength of current, to which the figures in the second column correspond. Thus, when the Morse key had been pressed down for eight seconds, the spot of light was just passing the 100th division of the scale, showing that the current had attained 77 per cent. of its maximum strength. One part of the arrival-curve might be constructed by using the entries in the first and third columns as coordinates.

The whole curve could not be obtained because the movement of the spot of light during the first four seconds was too rapid to allow of observation.

Table II. contains a similar set of observations made with 36 Daniell's cells instead of 72. By comparing the third lines of the two Tables, it is seen that the same percentage of the maximum strength is reached in the same time with both batteries, or, in other words, that the *electromotive force of the battery has no appreciable effect on the velocity with which the current is transmitted.*

All the variations of the received current are therefore in the Tables reduced to percentages, or to the variations which would have been observed if the permanent current due to the battery used had produced a maximum deviation of 100 divisions in each case. This condition could have been practically fulfilled, but was thought unnecessary, as no change of the battery would have altered the percentage of variation observed in the received current.

Table III. shows some observations for the arrival-curve with 1500 knots of cable in circuit.

Table VII. contains the result of a similar investigation for 1006 knots. The first and second columns of this Table contain similar entries to those in Table I.; the third column shows the division passed by the spot when the current was falling, after the Morse key had been released for the number of seconds entered above in the first column.

Thus, after the end A of the charged cable had been put in connexion with the earth-plate E (fig. 1) for 14½ seconds, the spot was just falling past the 15th division of the scale. As the maximum deviation had been 277 divisions, the spot had, during these

14½ seconds, traversed 262 divisions of the scale, or the received current had diminished 94·6 per cent. in that time. The fourth and fifth columns give these two numbers. It will be seen from these columns that, measuring from the starting-point, the spot of light traversed the same distance on the scale in the same time when the current was falling as when it was rising. From this we conclude that *the rate of decrease in the current received at* X *after the contact had been made for a given time with earth at* A, *was the same as the rate of increase observed after making contact with the battery at* A *for an equal time.*

Table XII. contains a very perfect set of similar observations with 2192 knots in circuit. The arrival-curves for 1006 knots and 2192 knots constructed from Tables VII. and XII. are shown in fig. 7, Plate L.

The same connexions (fig. 1) were used to test the effect of practical signals, the Morse key being moved up and down in time with a metronome. The signals sent were the dot and dash, or dot and line, singly and combined. These signals are the simplest of all, but the conclusions drawn from them are applicable to all other signals depending on the time during which a given strength of current flows.

The headings of the several columns explain the contents of Table IV., which shows the observations made when various signals were sent at various speeds through 1500 knots of cable. Tables VI., XIII., and XIV. contain similar observations made with other lengths of cable in circuit. It should be observed that the effects recorded are those which occur when the same cycle of operations has been constantly repeated for some time, and are quite distinct, as will presently be shown, from the effects produced when signals of the same kind are for the first time sent through the cable.

The first set of observations recorded in Table IV. may be explained as follows. The metronome was set so as to beat 130 times in the minute. The Morse key alternately connected the cable at A with a battery of 72 Daniell's cells, and with the earth-plate for 0·462 second. The signals sent are called dots, because the sixty-five short contacts with the battery, each followed by an equal contact with the earth, would, through a short cable or air line, have transmitted sixty-five distinct currents, each capable of printing on the common Morse receiving instrument sixty-five equally spaced dots. While the contacts were regularly repeated, the spot of light moved steadily back and forward from the 85th to the 80th division of the scale. By reducing these deviations to a percentage of the maximum deviation (200 divisions), we obtain the numbers 42·5 and 40. The variation of the strength of the received current was therefore 2½ per cent. All these numbers are entered in the several columns of the Table.

The figures annexed to the Tables show by curves the changes of the received current. The abscissæ of the curves correspond to intervals of time, and are taken from the fourth column. The ordinates correspond to the strength of the received current at each moment, reduced to a percentage, and are taken from the eighth column. The ordinates, instead of being measured from a true base-line, are measured from a horizontal dotted line, of which the ordinate is 50.

The dots first entered (Table IV.) appear as an even wavy line; the lowest point of each wave is 10 parts, and the highest point 7¼ parts below the dotted line, corresponding to the true ordinates from the base, viz. 40 and 42¼. The top and bottom only of the waves are fixed by the observations.

The second kind of signals are called dashes, because if sent through a short cable or air line, they would print a succession of dashes or lines, separated by short spaces equal to those separating dots sent at the same speed. To do this the contact with earth is made the same as for a dot, but the contact with the battery is made twice as long. Examples of the dash will be found in Tables VI. and XIII.

The effect of combining these two primary signals was tried by sending alternate dots and dashes; the results are entered in the Tables. The effect of one complete cycle of operations is shown in the figures annexed to the Tables by that part of the curve drawn with a thicker black line. Thus in the second dot and dash curve of Table IV. the dot curve begins with the ordinate 53·2; the first battery-contact slightly increases the current, till the ordinate of the top of the dot curve becomes 55·5. The first earth-contact diminishes the current, so that the ordinate at the end of the dot or beginning of the dash curve is 48·0; the next battery-contact, being a long contact, raises the dash curve to 61·7. The second earth-contact lowers it to 53·2, when the cycle recommences.

The numbers in the two last columns of the Tables IV., VI., XIII., and XIV., with the figures annexed, are all directly comparable, for they all represent the results reduced to a percentage, and are consequently constant for each length, being independent of any change in the battery.

These observations do not give the retardations properly so called, *i. e.* they do not show the time separating the contact made at A from the effect produced at X, but they establish several conclusions of greater importance than the knowledge of this retardation.

It will be seen (Table VI.) that when 66 dots per minute were sent into 1802 knots of cable at A, a constant current was received at X, in which no oscillation could be seen corresponding to the signals sent*.

The same phenomenon was observed with 2192 knots in circuit, when more than 50 dots per minute were sent. The effect produced at X by these rapidly repeated dots was almost exactly that which would have been observed if the cable at A had been permanently connected with a battery of about 30 cells. In moving the Morse key up and down, a little time elapses between the contact with earth and that with the battery, during which the cable is really insulated at A. This lost time caused the received current to be equal to only 41·6 in one case and 42·9 in the other instead of 50 per cent. of the maximum permanent current, as would certainly have been the case if the sums of the battery and earth contacts had respectively occupied exactly the half of each minute.

* The immobility of the spot could not be accounted for by the inertia of the mirror and magnet, which, when in vibration, moved so rapidly that the oscillations could not be counted. Similar observations made with a galvanometer, the needle of which oscillated slowly, would lead to most erroneous results.

It is certain that in the two cases named the received current did not vary 1 per cent.; here therefore we find one positive *limit to the rate of transmission.* No doubt oscillations of considerably less than 1 per cent. might be observed and recorded by employing a more sensitive instrument and stronger batteries; but we clearly see that the useful effect produced rapidly decreases as the number of signals per minute increases, and therefore that, however sensitive the instrument and powerful the battery, signals sent at more than a certain rate will fail to cause any appreciable useful effect at the receiving end; and we may safely conclude *that in all submarine cables there is a limit to the number of signals which can be sent per minute, a limit which cannot be exceeded by any ingenious contrivance.*

Fifty-six dots per minute were distinctly visible when sent through 1802 knots, and 40 dots when sent through 2192 knots. The mean strength of the currents showing these dots is less than half the maximum permanent current, because of the time lost in moving the Morse key, as already explained. The curves showing these dots appear therefore below the dotted line representing the middle of the scale.

As the speed of sending decreased, the amplitude of oscillation of the spot or variation of the current increased, but the mean strength of the current remained nearly constant.

When dashes were sent (*i. e.* when the length of the battery-contact was made twice as long as the earth-contact), the mean strength of the received current was much higher, being above the middle of the scale.

The effect of dashes could thus, and thus only, be distinguished from that of dots sent at a lower speed. For instance, dashes sent through 1802 knots (Table VI.) when the metronome beat 84 caused a 6 per cent. oscillation, and dots sent when the metronome beat 60 caused very nearly the same oscillation; but the strength of the current due to the dashes varied from $53\frac{1}{2}$ to $59\frac{1}{2}$, whereas that due to the dots varied from 43 to 49. In the corresponding curves the dashes appear above the dotted line and the dots below. This effect will be easily understood when it is remembered that while dots are sent, the end A of the cable is altogether in contact with the earth for nearly half of each minute, but when dashes are sent, it is in contact with the earth for only about one-third of each minute.

When the dot and dash are sent alternately, the effects, differing considerably from those produced when each is sent continuously, can be best studied in the curves annexed to the Tables.

The top of the dot curve is higher, and the bottom does not go so low as when dots only are sent, whereas the top and bottom of the dash curve are both lower than when dashes only are sent; *but the bottom of the dash curve does not go so low as the bottom of the dot curve.* This was seen in every instance, but was most apparent at the higher speeds.

The strength of the received current due to the long battery-contact during the dash is naturally greater than that caused by the shorter contact during the dot; and as the

connexion with earth after the two signals is only of equal duration, it is clear that the received current will not fall so low after the dash as after the dot, and this is precisely the effect shown in the curves. The beginning and end of the dot are at different heights, and similarly the beginning and end of the dash are at different heights, making altogether a very irregular curve, especially at the higher speeds.

This irregularity very seriously interfered with the distinctness of the received signals, although the change of current could be followed throughout by watching the spot. At a high speed the dot appeared as a mere pause followed by a fall, instead of a little rise followed by an equal fall; and if the dots and dashes had been irregularly combined, it would have been impossible to disentangle them, as received, by the eye. If a receiving instrument had been used like the common Morse receiver, simply marking the time during which the received current was above or below a given strength, the signals would have failed to give any intelligible record even at a very low speed: this is shown by the fact that it is impossible to draw a horizontal line intersecting both the curve of repeated dashes and that of repeated dots, even for the very lowest speeds recorded in each Table.

Thus, long before the limit is reached at which signals cease to produce any change at the receiving end, the interference of one signal with another causes so great a confusion in the currents received as to put a fresh limit to the practicable speed of transmission.

This confusion is still further increased by the effect of a pause in the signals between letters, words, or sentences.

During all intervals the cable is left in connexion with the earth at A; and if the pause lasts a little while, the current at X falls to nothing, or nearly nothing, when the effect of the first signals sent is to cause an unintelligible succession of sudden increments in the received current, until, after a certain number of contacts, a permanent mean strength of current is attained, at which regular signals might become intelligible. The higher the speed the greater the number of contacts required for this purpose; for instance when 1802 knots were in circuit, the following Table gives the number of dots required to bring the spot to the mean position in which it was maintained by regular signals.

Beats of metronome.	Dots required to raise current to 42 per cent. of maximum.
92	6
84	6
72	4
60	3
50	.
40	2

The curve in fig. 3, Plate XLIX. roughly represents the variations of the received current when the operator begins to send the dots regularly through a cable which has

been fully discharged. Similar but converse effects would be observed if the line were left long in contact with the battery before the signals began.

This irregularity has hitherto put the practical limit to the rate of transmission through long submarine cables. When this rate is exceeded, a dot sent may at one time cause a great rise in the received current, at another time it will barely arrest a fall, and thus similar signals at one end are found to produce utterly dissimilar effects at the other. No change in the battery has the smallest effect on this interference, nor can any delicacy in the receiving instrument disentangle the confusion, which, it should be observed, is totally distinct from the retardation of the signals.

It would matter little that signals should appear in America even a minute or so after they had been made in England, provided the same signal at the sending end always produced the same effect at the receiving end. The experiments show how far this is from being the case.

The usual mode of avoiding this confusion is to signal at so slow a rate that every dot causes a very large percentage of variation in the received current, while the dash causes nearly the maximum current which would be received from a permanent contact with the battery.

In air lines, or in short submarine cables, or in long submarine cables with large conducting wires thickly covered, this plan does not entail too slow a speed for practical work; but to avoid confusion in this manner when working through 2200 knots of the Red Sea cable, it would be necessary to reduce the speed to less than 10 dots per minute, whereas 40 dots or more could be received but for the interference.

Hence we conclude *that there is a wide margin between the limit set to the speed of transmission by the gradual diminution of the received signals and that set by their interference.*

If interference could be prevented by any change in the signals, it was clear that the capabilities of any given cable would be increased at least fourfold.

Reverse currents have been much advocated, on good authority, as a means of greatly increasing the rate of signalling, and their effect was therefore examined, although it was not thought probable that the interference would be diminished by their use. By "reverse currents" the use of alternate positive and negative currents is meant. The negative current substituted for the earth-contact is supposed by its advocates in some way to clear the line and prepare the way for a positive signal.

The connexions used during the experiments on "reverse currents" are shown in fig. 4, Plate XLIX. The first contact sent a positive, and the second contact a negative current through the line.

The effects of single and reverse currents were directly compared on 1165 knots of cable. Tables VIII. and IX. show observations of the arrival-curve and signals when a positive current from 72 cells and an earth-contact were used. Tables X. and XI. show a similar set of observations when a positive current from 42 cells and a negative current from 30 cells were used. By keeping the same total number of cells in each

case, the difference of potentials between the two sources of electricity alternately in connexion with the line was maintained nearly equal. Tables VIII. and IX. are similar to those already described.

The observations in Table X. were made in almost the same manner as those in Tables VIII. and IX., but the following description may make the meaning of the entries more distinct.

The Morse key when untouched left the negative battery connected with the line, and the spot of light then stood at 113 divisions to the left of zero; when the key was permanently pressed down, the spot stood at 157 divisions to the right of zero. All deviations to the right are entered as positive, those to the left as negative. Four seconds after the key was pressed down, the spot passed the 100th division to the right; four seconds after the key was released, it passed to the 60th division on the left. In the first case it had traversed 213 divisions in four seconds, in the second case 217 divisions, or 78·8 and 80·3 per cent. respectively of the sum of the two deflections 157 and 113.

On examining the last columns of Table X. we find that in any given time after moving the key, the spot traversed an equal length of the scale whether the change was from positive to negative or from negative to positive, or, in other words, *the rate of decrease in the current received at* X *after contact had been made with the negative battery at* A *for a given time was the same as the rate of increase observed after making contact at* A *with the positive battery for an equal time*,—a conclusion exactly analogous to that arrived at when single currents were used.

Moreover, comparing the last columns of Tables VIII. and X., we find that the spot traversed the same distance in the same time in each case, and therefore that the rate of increase and rate of decrease, caused by reverse currents, is exactly the same as that observed when single currents are used.

The arrival-curves from the two Tables are shown in figs. 5 & 6, Plate XLIX.

The curves are identical in shape, and differ only in their position relatively to the zero-line.

Thus the ratio between the ordinates of the arrival-curve is the same whatever the two sources of electricity at A, or the potential of the earth at X may be.

Hence we conclude,

1st. That the absolute change in the strength of the received current during a given time after a change in the contact at A, is not influenced by the potential maintained at X, but is simply proportional to the difference of potentials or electromotive force between the two sources of electricity alternately connected with the cable at A.

2nd. That the rate of change is independent of the potentials both at A and X.

It was now clear that the alternation of negative and positive currents could have no effect on the rate of signalling, but to avoid all cavil a few experiments were made with the usual signals.

The results are given in Tables IX. and XI. The signals sent by the reverse currents

were a little above the zero-line, those sent by the single currents were, as usual, near the middle of the range. This was the only difference observed; the amplitudes and relative position of the dot and dash were identical. The use of reverse currents, therefore, *does not alter the limit set by the gradual diminution of the received signals, nor that set by their interference.*

It is just possible that some small effect may be produced by a difference in the insulation when reversals are used, but there is no reason to suppose that this difference would be in their favour.

Abandoning reverse currents, the author was led to seek some other remedy for the confusion observed. One phase of this confusion might be described by saying that the mean strength of the current rose above 50 when dashes were sent, and fell below it when dots were sent, so that the dots and dashes appeared on different parts of the scale. The high position of the dash was due, as has been shown, to the comparatively short contact at A with earth after the long battery-contact. By making the second or earth-contact longer, the dash would be brought down in the scale. If the earth-contact were made equal to the battery-contact, the dash would simply become a dot sent at a slower rate. The mean strength of the current during the slow or long dots would be the same as that during the quick or short dot. The bottom of the long dot curve would be lower than the bottom of the short dot curve, and therefore, when the long and short dot were combined, there would still be considerable confusion. Moreover, if a Morse receiver or analogous instrument were used, the spaces separating the long dots would be twice as long as those separating the short dots, and this unequal spacing would cause fresh confusion.

These effects, consequent on making the second contacts always equal to the first, were well seen when the signals called A* were sent*. The tendency observed in the original dot and dash was over-corrected. The dash now fell too low, and the dot not low enough, so that the confusion was nearly as bad as before; but the required correction was clearly enough pointed out. If, instead of keeping the *mean* strength of the current constant, the current at the *end* of each signal could be kept the same, the passage from one signal to another would cause no confusion, for the beginning or end of a dot would be exactly like the beginning or end of a dash. It was plain that the current at the end of a dash could be brought to any required point (and therefore to the point at which dots finished) by simply altering the proportion of the second to the first contact. Experiment had shown that the second contact was too short when made only half the length of the first, and too long when made equal to the first; no doubt some intermediate length would fulfil the required condition that the dashes should begin and end at the same division of the scale as the dots. The experiment required to prove this could clearly not be tried by aid of the metronome, and the apparatus shown in fig. 8 was therefore arranged so as to make contacts of any required proportion.

* So called because the dot and dash, followed by a short pause, represent the letter A in the Morse alphabet.

A strip of paper (figs. 8 & 9, Plate L.) was prepared with two parallel rows of alternate holes. This paper was joined so as to form an endless band, and was drawn by the roller R under two little bent wires *b* and *e*, placed abreast, so that each alternately came in contact with the metal plate L through one of the holes in the paper. The plate L was connected with the cable, the wire *b* with the battery, and the wire *e* with earth. As the paper was drawn along under the wires, the alternate battery and earth contacts sent signals through the cable, and the length of the holes in the paper determined the relative length of the contacts.

The first or battery-contact was made through the upper row of holes (fig. 9), the earth-contact through the lower row. Dots were sent by two equal holes, dashes by two longer holes, of which the upper bore to the lower the proportion of 5 to 4, corresponding to the relative length of contacts desired. The length of the two dash contacts was made equal to two pairs of dot contacts.

It was expected that if the right proportion between the first and second dash contacts had been adopted, all confusion from irregular combinations would be avoided; but during any pause, such as is practically required to separate groups of signals, the spot or current would still fall towards zero if the line were left in contact with the earth (or even if insulated at one end), so that the first signals sent after a pause would still cause mere irregular and unintelligible changes in the received current. To avoid this second source of confusion, it was necessary to maintain the received current, during any pause, at the constant final strength to which it returned at the end of each oscillation during a series of signals.

If this were done, the first signal would begin where the last left off, and each signal might be expected in all cases to produce one invariable and intelligible effect.

There were two obvious means of keeping up the current during a pause. The line might be left in contact with a third source of electricity* just sufficiently powerful to maintain the required strength of current, or a very rapid series of contacts might be made alternately with the full battery and with earth. Experiment had shown that such a series of contacts would maintain the current at the receiving end sensibly constant, and the strength of this constant current could be easily adjusted by varying the proportion between the first and second of these very short contacts, increasing the length of the first contact to raise the current, and increasing the length of the second contact to lower the current.

This second plan was easily carried out by the perforated paper. Where a pause was

* When reverse currents are used, if the line is put in contact with earth during a pause, the confusion of the first signals will be much lessened; the earth then acts as the third intermediate source of electricity alluded to in the text. This plan has to some extent been adopted in practice by Messrs. Siemens and Halske, by means of a key invented by Mr. L. Loeffler. This benefit, which may perhaps account for the fancied superiority of reverse currents, might be equally obtained with simple currents by connecting the line during each pause with half the battery. Mr. C. F. Varley informed the author that he also has used a similar key for a considerable time.

required, little holes were cut in the paper to make contacts in pairs, each pair half the length of those used for a dot. In fig. 9 these short openings are shown where the word "space" is written. This arrangement was perfectly successful with 1500 knots in circuit on the very first trial; and although other strips of paper were tried with other proportions between the contacts, none gave better results than those first adopted. When the paper was steadily drawn along, the signals appeared on the galvanometer with all the regularity that could be wished: during the pauses, the light stood trembling at one division on the scale, a dot caused a slight rise followed by an equal fall, and the dashes produced a greater and longer oscillation, at the end of which the spot always returned to the one constant final strength.

A still more decisive test was next made, by substituting a relay and Morse marker for the galvanometer; fig. 10, Plate L. is an exact copy of the signals which were then received, and shows faithfully the slight irregularities which did occur. The only serious flaw in the whole set of signals is shown at the beginning, between A and B, where some dots and a space contact made only unintelligible marks. This flaw invariably occurred at the same place; it was shown equally by the galvanometer and the relay, and for some time the cause could not be discovered. By carefully watching the paper strip, it was at last seen that when the joint of the endless band passed through the rollers R (fig. 8) a little hitch or pause occurred, and that this slight irregularity of speed caused a corresponding confusion in three signals. This accident showed the accuracy of proportion required between the various contacts.

Taking this hitch as the beginning, we next see six well-spaced dashes, three pairs of dots and dashes, one space, one dot, one space, one dash, a long pause, a dot, a long pause, a dash, a short pause, a dot, a dash, and a succession of dots.

In this series every possible difficulty which could arise from interference or confusion was encountered and successfully overcome. The rate was about forty-five dots per minute, and the oscillations for a dot must have been about 5 per cent.*

Signals sent at a much higher rate could have been distinctly received, but the drawing-rollers could only be driven at one speed.

The apparatus was next tried with 1800 knots in circuit: the signals could be read without difficulty on the galvanometer; but to increase the range and to facilitate the adjustment of the relay the battery power was increased, when not only could the regular dots and dashes be received, but even the short space contacts gave distinct legible signals; so that the three sets of signals of three different lengths appeared, without confusion, recorded by the relay. The shortest signals were received at the rate of ninety per minute; and from Table VI. it will be seen that even sixty dots per minute through this length reduced the oscillations to less than 1 per cent. of the permanent maximum strength. Hence we may conclude that, *by the means described, or by*

* When the relay was used the galvanometer could not be observed, for the motion of the soft iron used in the relay induced short currents, causing rapid vibrations of the spot of light.

analogous means, signals can be sent without confusion at any speed which will allow the shortest signals used to cause a sensible variation in the received current.

The cable was available for a few days only, the apparatus used was very imperfect, the paper frequently tore, the openings in it were cut by hand one by one, the speed of the drawing-rollers was far from regular, the relay was difficult to adjust, owing to residual magnetism in the electro-magnets, and the author could give but a small part of each day to the experiments; in spite of these disadvantages, the results obtained were so definite as to leave no doubt of the important conclusion stated above.

No further experiments could be made; but indeed no further improvement appeared possible, except in the mechanism for making the required contacts, and in the choice of signals which should give the greatest number of words with the smallest number of currents. Neither of these points can fitly be treated of in the present paper.

Before proceeding to compare the results obtained with the deduction from mathematical theory, or to apply the conclusions to cables in practical use, it will be well to consider how far the special disposition of the cable may have affected the value of the experiments.

The experiments were made through dry cables, lying in large close coils, whereas the cable when in use lies extended under water. It is found in practice that the insulation and charge of an iron-cased cable is little affected by submersion; but coiling is generally believed to cause an additional impediment to the transmission of signals, and it might certainly be expected that this difference of condition would cause some discrepancy between the experiments described and the results of practice: but since the mathematical theory is framed to meet the case of a submerged and extended cable only, whenever the conclusions experimentally deduced are found to be in accordance with the deductions of theory, it is clear that the experiments and the theory mutually confirm one another, and that the conclusions may be safely applied to the practical case of an extended and submerged cable; for it is impossible to suppose that the dry and coiled state of the cable, not contemplated in the theory, should nevertheless exactly compensate its errors, or that results due only to an accidental arrangement of the cable should by chance coincide with deductions from a defective hypothesis.

When, on the other hand, the results obtained differ from those given by theory, or even when the theory affords no confirmation of the experimental conclusions, we must forbear to extend these conclusions to the practical case of a straight cable.

The arrival-curve obtained by experiment is similar in general appearance to that given by Professor THOMSON in "The Theory of the Electric Telegraph*." The identity of the curve obtained from the increase with that obtained from the fall of the received current, follows from equation (3.) in the same paper. The described effects of using alternate currents follow from the principle of superposition, by which also the effects of the increased speed might be shown in diminishing the received signals.

* *Vide* Proceedings of the Royal Society, May 1855, and Philosophical Magazine, S. 4. vol. xi. p. 146.

An example of the confusion arising from interference between successive signals has been given by Professor THOMSON in his evidence before the Committee appointed by the Board of Trade to inquire into the construction of submarine telegraph cables. Professor THOMSON has also informed the author that the compensation derived from experiment, as explained above, is such as theory would demand, but that he has not yet verified the exact proportion required between the first and second contacts*.

Thus every conclusion hitherto stated is in accordance with the mathematical theory, and may therefore without hesitation be applied to submerged and extended cables.

The arrival-curves (fig. 7, Plate L.) do not, however, accurately correspond with that given by Professor THOMSON. The dotted line shows the calculated curve, drawn so as nearly to agree with the experimental curve from 2192 knots, at its origin; the difference between the two curves towards the end is very great. The experimental curve approaches its limiting height much too slowly after the first few seconds; one part of the curve from 1006 knots is shown on the same figure, and by theory the abscissæ of the two curves corresponding to equal ordinates should be directly as the squares of the lengths. At the origin of the curves this is approximately the case, making a small allowance for the constant resistance of batteries and instruments; but towards the end of the curves this is far from being the case. Some of the causes of the discrepancy may disappear in straight cables, but meanwhile the constants required in the mathematical theory cannot be with confidence derived from these curves or Tables.

It is generally believed that coiling increases the retardation, and the curves obtained might be pointed to as confirming this opinion. It is certain that a mutual electromagnetic induction of considerable importance does occur between the different parts of the coils†, and probably some part of the discrepancy between the observed and calculated curves is due to this cause. But the varying resistance of gutta percha, unknown when the theory was framed, also accounts for a considerable difference between the results of observation and calculation. The allowance to be made for a constant uniform leakage such as would occur if the resistance of the gutta percha were uniform, is described by Professor W. THOMSON in the "Theory of the Electric Telegraph;" but the author of the present paper discovered that the resistance of gutta percha, such as was used for the Red Sea cable, increased more than 60 per cent.‡ during positive or

* Professor THOMSON has also stated that he has long been acquainted with some other modes of producing the required regularity, and one of his methods is alluded to in the evidence before the Board of Trade Committee. *Vide* also Proceedings of the Royal Society, Dec. 1856, and Philosophical Magazine, 1857, where the mathematical principle of the compensation is fully stated.

† *Vide* paper read by Professor THOMSON at the British Association, Aberdeen, 1859, and letter by Professor W. THOMSON and the author, published in the 'Philosophical Magazine,' 1861; also a letter from Mr. F. C. WEBB in 'The Engineer,' August 1859.

‡ These numbers are calculated from data in the paper by the author read before the Royal Society in 1860, and published in abstract in the 'Proceedings' of last year, and in the 'Philosophical Magazine' for 1861; also in full in the Appendix to the Report of the Committee of the Board of Trade on the Construction of Submarine Cables, 1861.

negative electrification, and that a great part of the observed change was completed before the end of the first minute after the cable was connected with the battery. This gradual improvement of insulation would gradually increase the received current long after all inductive phenomena had ceased. For instance, the resistance of the total gutta-percha sheath of 2192 knots at 60°, after negative electrification for about 15″, would be 104×10^{10} absolute British units; after one minute, this resistance would increase to 132×10^{10}. The resistance of the conductor was about 55×10^{10}.

If the insulation had remained constant at the first-named figure, the final maximum arriving current would have been only 78·4 per cent.* of the entering current; and if the insulation-resistance had remained constant at the second figure, the final arriving current would have been 82·4 per cent. of the entering current. It is not therefore surprising that the observed curve, subject to the influence of imperfect and varying insulation, should not more perfectly coincide with the theoretical curve, in which perfect and constant insulation is assumed. When allowance is made for the change in the entering current due to the change in the total resistance of the circuit caused by the change in the insulation-resistance from 104×10^{10} to 132×10^{10}, the final arriving current with the lower insulation would by calculation be about 97 per cent. of the arriving current with the higher insulation, and this proportion very exactly corresponds with the slow increase observed during the last forty seconds of the minute. This increase has therefore no connexion whatever with the retardation properly so called.

The identity of the curve of increase with the curve of decrease seems to show that the apparent increase of the resistance of the gutta percha is rather due to an absorption of electricity which is again given out, than to a real change in the conductivity of the material†.

The effect of varying insulation would be much less felt during the actual transmission of signals, for then the greater part of the cable is constantly electrified in one manner, and the resistance of the gutta percha under such circumstances remains sensibly constant; we might therefore here expect a better agreement between theory and observation.

In order to examine the results of the experiments on repeated signals, the number of dots sent per minute, and the corresponding amplitude of oscillation observed in the received current, might be used respectively as abscissæ and ordinates, to give a curve expressing the rate at which, for each length of cable, the effect of the signals diminished as their speed increased; but, by the mathematical theory, the time required for any electrical operation varies as the square of the length of the cable. The product of the square of the length into the number of dots producing a given amplitude of variation should therefore be constant for all lengths of the same cable; and by using this product as an abscissa, instead of the simple number of dots, one curve should give the

* Appendix, Section I.

† The truth of this conclusion has been established by the results of some experiments on the Malta-Alexandria cable, made by Dr. Esselbach, and received by the author since writing the above.

amplitudes for all speeds through all lengths of cable; and conversely, the observations made on various lengths should, when thus geometrically represented, agree in defining one curve. The agreement between theory and observation may be very readily tested by comparing the observations through various lengths in this manner. But Professor THOMSON has also stated *, as a development of the theory, that if the resistance of the battery and receiving instrument bear but a small proportion to the total resistance of the cable, their effect in retarding and weakening the signals will be sensibly the same as that of adding an equal length of actual cable with its usual electrostatic capacity. (Evidence before Board of Trade Committee.)

It will thus be necessary, in comparing the observations, to add in each case 160 knots, equivalent to the resistance of the battery and galvanometer, to the length of the cable. Table XV. and fig. 11, Plate LI. show the results of the comparison. The first and second columns of the Table give the number of beats and corresponding amplitudes, extracted from Tables IV., VI., and XIII. The third column contains the product of the number of beats into the square of the length of the cable. The fourth column gives the similar product when 160 knots has been added to the length of each cable.

Fig. 11 gives the geometrical representation of the observations made by using the entries in the second and fourth columns of the Table as ordinates and abscissæ respectively.

The star, cross, and circle respectively denote observations with 1500, 1802, and 2192 knots in circuit. All these marks fall sensibly on one curve, affording *a perfect experimental proof that the rate of transmission does vary inversely as the square of the length, whether by rate of transmission be meant that speed at which the repeated signals fail to produce any sensible effect, or the rate producing so great an amplitude that common hand signals can be received without confusion.*

Moreover, it will be found that the curve is more accurately defined by taking the abscissæ from the fourth than from the third column; verifying Professor THOMSON'S conclusion as to the effect of the resistance of the battery and receiving instrument. These points have been much debated, but no doubt should now be felt of the soundness of the theoretical conclusions.

The above is neither the only nor the most remarkable confirmation of the mathematical theory. Professor THOMSON has been so kind as to give the author a Table (XVI.†) of calculated ordinates for the curve in question‡. The full black line (fig. 11) was constructed from this Table, and coincides with the recorded observations in the most striking manner; no more perfect verification of complicated mathematical calculations was probably ever obtained by experiment.

The curve shows at once the relative number of signals per minute which will pro-

* *Vide* Evidence before the Committee of the Board of Trade on the Construction of Submarine Cables, A.D. 1861, p. 125.

† Appendix, Section II.

‡ Proceedings of the Royal Society, 1855 and 1856, and Philosophical Magazine, 1856 and 1857.

duce the various amplitudes in any one length of cable; thus we see that if an amplitude or variation in the received current of 1 per cent. will suffice for distinct signals, twice as many signals can be sent through any given cable as if an amplitude of 7 per cent. is required, or four times as many as if an amplitude of 25 per cent. is required. The latter amplitude is probably necessary for hand signalling, but our experiments have shown that less than 1 per cent. is sufficient when a proper compensation is made. The coincidence between theory and observation places it beyond doubt that the curve truly expresses the relation between the speeds and amplitudes for straight as well as for coiled cables; and if the amplitude at any one speed through any one straight cable were known, the amplitude at any other speed through any other cable of the same materials might be calculated from the curve with certainty; but unfortunately this fact is wanting. There is no proof that the absolute amplitude observed through the coiled cable would remain unaltered if the cable were extended; on the contrary, it is very generally believed that it is easier to signal through a straight than a coiled cable; and if this be so, the amplitude would increase as the cable was laid. Although, therefore, the constants for the mathematical theory might easily be calculated from the values of the coordinates of the curve given by the observations, these constants would probably be inapplicable to straight cables.

Assuming, however, for a moment the identity of a coiled and extended cable, it may be interesting to calculate the amplitudes which would correspond to the rates of signalling recorded for various cables.

For the Red Sea cable the amplitude is found by taking the ordinate corresponding to the abscissa given by the product of the square of the length into twice the number of dots per minute. The speed giving the same amplitude through any other cable of different dimensions, but of equal length, is obtained by a simple proportion.

The author has been informed that ten words per minute have been sent through 640 knots of the Red Sea cable, but that seven words was the more usual speed. The former would correspond to an amplitude of 20 per cent. for the dots*, the latter to about 35 per cent. 1·1 word per minute was sent through the Atlantic cable and received by a relay; this speed would correspond to an amplitude of about 8 per cent.; 2·4 words per minute (the ordinary rate of signalling from Newfoundland having been forty-one dots per minute) were received through the same cable by Professor THOMSON'S galvanometer†, corresponding to an amplitude of little more than 1 per cent.

Ninety dots per minute, the speed of the message sent by the perforated paper, would,

* Seventeen dots per word.

† An instrument similar to that used in this research: the observer could therefore follow every change in the received current, and disentangle the meaning of signals which would have produced only hopeless confusion on a relay, or other instrument with a fixed zero.

for 1802 knots, give by the curve an amplitude of 0·3 per cent. only, and there is no reason to doubt this estimate.

In conclusion, the experiments, so far as they went, were successful. They have shown the relative effects of signals transmitted at various speeds through various lengths; they have shown how little the results are affected by changing the power or arrangement of the batteries; they have shown the nature of the ultimate limit set to the rate of signalling by the gradual diminution and disappearance of the signals, preceded by their mutual interference.

The coincidence between theory and observation on these points gives good proof of the soundness of the theory, and permits the extension of the conclusions to the case of a submerged and extended cable. The experiments have also given well-defined curves fully expressing the retardation experienced through the cable as it lay in coils; but owing to this arrangement, the observations cannot be said to fix either the retardation or the absolute effect of signals through a straight cable. A few observations made in the same manner on a sound cable in actual use would be sufficient for this purpose.

Finally, the research has proved that the rate of signalling through a given cable can be very materially increased by removing the confusion or interference of successive signals, and has led to the discovery of one method of effecting this object.

In the present paper, the phenomena depending on the length of the cable, together with the rate and manner of signalling, have alone been considered. The absolute measurement of the effects depending on the materials and dimensions of the insulated conductor will probably form the subject of another research, completing the practical examination of the mathematical theory.

TABLE I.—Arrival-curve for 2168 knots, in 10 coils, with 72 p.p. July 26, 1859.

Maximum deflection caused by permanent current from 72 p.p. ... 130[d].

Seconds after making contact with battery	4	5	5	6	6	7	8	11	15	21	51
Division of scale passed by spot as the current rises at far end of line	50	60	70	80	80	90	100	110	120	125	130
Reduced distance traversed by spot after contact has been made with battery for each number of seconds	38·5	46·2	53·9	61·6	61·6	69·3	77·0	84·7	92·4	96·2	100

TABLE II.—Arrival-curve for 2168 knots, in 10 coils, with 36 p.p. July 26, 1859.

Maximum deflection caused by permanent current from 36 p.p. ... 63½[d].

Seconds after making contact with battery	7½	8	10½	16½	18	19
Division of scale passed by the spot as the current rises at far end of line	50	50	55	60	60	60
Reduced distance traversed by spot after contact has been made with battery for each number of seconds	78·5	78·5	86·4	94·2	94·2	94·2

TABLE III.—Arrival-curve for 1500 knots, in 8 coils. July 27, 1859.

Maximum deflection caused by permanent current from 72 p.p. ... 200d.

Seconds after making contact with battery	6½	6½	8½	14	33
Division of scale passed by the spot as current rises at far end of line	170	170	180	190	200
Reduced distance traversed by spot after contact has been made with battery	85	85	90	95	100

TABLE IV.—Signals through 1500 knots, in 8 coils. July 27, 1859.

Maximum deflection caused by permanent current from 72 p.p. ... 200d.

1. Rate of movement per minute.	2. Signals sent.	3. Source of electricity in contact with line at near end.	4. Duration of contact at near end in seconds.	5. Limit of deflection at far end. First observation.	6. Second observation.	7. Mean limit of deflection caused by contact.	8. Reduced mean limit of deflection caused by contact.	9. Reduced mean amplitude of oscillation caused by two contacts.	Diagrams showing the changes of current caused at the end of the line by the signals. Vertical scale $\frac{1}{100}$th of an inch = 1 division (strength of current). Horizontal scale $\frac{1}{10}$th of an inch = 1 second (time).
130	Dots.	72 p.p.	0·462	85	—	85	42·5	2·5	
		E.	0·462	80	—	80	40		
100	Dots and dashes.	72 p.p.	0·6	112	111	111½	55·2	Reduced amplitude of corresponding dots 48.	
		E.	0·6	100	95	97½	48·4		
		72 p.p.	1·2	122	125	123½	61·7		
		E.	0·6	110	110	110	55		
92	Dots.	72 p.p.	0·652	85	—	85	42·5	5·0	
		E.	0·652	75	—	75	37·5		
	Dots and dashes.	72 p.p.	0·652	110	112	111	55·5		
		E.	0·652	95	97	96	48		
		72 p.p.	1·3	122	125	123½	61·7		
		E.	0·652	105	108	106½	53·2		
72	Dots.	72 p.p.	0·833	95	—	95	47·5	10·0	
		E.	0·833	75	—	75	37·5		
	Dots and dashes.	72 p.p.	0·833	115	112	113½	56·7		
		E.	0·833	90	92	91	45·5		
		72 p.p.	1·666	130	135	132½	66·2		
		E.	0·833	100	105	102½	51·2		
60	Dots.	72 p.p.	1	100	—	100	50	12·5	
		E.	1	75	—	75	37·5		
	Dots and dashes.	72 p.p.	1	116	121	118½	59·2		
		E.	1	85	90	87½	43·7		
		72 p.p.	2	140	140	140	70		
		E.	1	100	100	100	50		

TABLE V.—Arrival-curve for 1802 knots, in 9 coils. July 28, 1859.

Maximum deflection caused by permanent current from 72 p.p. ... 168d.

Seconds after making contact with battery or with earth	5½	6½	7	8	9½	11½	15
Division of scale passed by the spot as the current rises at far end of line	130	135	140	145	150	155	158
Reduced distance traversed by spot after contact has been made with battery	77·3	80·3	83·3	86·3	89·2	92·2	94

TABLE VI.—Signals through 1802 knots, in 9 coils. July 28, 1859.
Maximum deflection with 72 p.p. ... 168d.

Beats of instruments per minute.	Signals sent.	Battery of electricity in contact with line at near end.	Duration of contact at near end.	Limit of deflection at far end. First observation.	Second observation.	Mean limit of deflection caused by contact.	Reduced mean limit of deflection caused by contact.	Reduced mean amplitude of oscillation caused by two contacts.
132	Dots.	72 p.p.	0·455	70	—	70	41·6	0 less than 1/4
		E.	0·455	70	—	70	41·6	
112	Dots.	72 p.p.	0·536	76	—	76	45·2	1·2
		E.	0·536	74	—	74	44	
100	Dots.	72 p.p.	0·6	75½	—	73½	43·4	1·8
		E.	0·6	70	—	70	41·6	
92	Dots.	72 p.p.	0·652	74½	—	74½	44·3	2·7
		E.	0·652	70	—	70	41·6	
	Dots and dashes.	72 p.p.	0·652	90	85	87½	52	
		E.	0·652	85	80	82½	49	
		72 p.p.	1·3	85	90	92½	55	
		E.	0·652	90	85	87½	52	
84	Dots.	72 p.p.	0·714	75	80	77½	46·1	3·0
		E.	0·714	70	75	73½	43·1	
	Dashes.	72 p.p.	1·427	100	—	100	59·5	6·0
		E.	0·714	90	—	90	53·5	
	Dots and dashes.	72 p.p.	0·714	95	95	95	56·5	
		E.	0·714	85	86	85½	50·9	
		72 p.p.	1·427	100	100	100	59·5	
		E.	0·714	93	94	93½	55·6	
72	Dots.	72 p.p.	0·833	76½	81	79	47	3·9
		E.	0·833	70	75	73½	43·1	
	Dashes.	72 p.p.	1·666	112	—	112	66·6	7·1
		E.	0·833	100	—	100	59·5	
	Dots and dashes.	72 p.p.	0·833	97	—	97	57·7	
		E.	0·833	85	—	85	50·6	
		72 p.p.	1·666	105	—	105	62·5	
		E.	0·833	95	—	95	56·5	
60	Dots.	72 p.p.	1	80	85	82½	49	5·9
		E.	1	70	75	73½	43·1	
	Dashes.	72 p.p.	2	120	—	120	71·4	11·9
		E.	1	100	—	100	59·5	
	Dots and dashes.	72 p.p.	1	99	95	97	57·7	
		E.	1	85	80	82½	49	
		72 p.p.	2	110	112	111	66	
		E.	1	95	90	92½	55	
50	Dots.	72 p.p.	1·2	83	80	81½	48·5	9·2
		E.	1·2	67	65	66	39·3	
	Dashes.	72 p.p.	2·4	120	125	122½	72·9	17·9
		E.	1·2	90	95	92½	55	
	Dots and dashes.	72 p.p.	1·2	95	100	97½	58	
		E.	1·2	80	85	82½	49	
		72 p.p.	2·4	115	120	117½	69·9	
		E.	1·2	85	90	87½	52	
40	Dots.	72 p.p.	1·5	90	95	92½	55	14·8
		E.	1·5	65	70	67½	40·2	
	Dashes.	72 p.p.	3·0	125	130	127½	75·9	23·9
		E.	1·5	85	90	87½	52	
	Dots and dashes.	72 p.p.	1·5	100	102	101	60·1	
		E.	1·5	72	80	76	45·2	
		72 p.p.	3·0	120	125	122½	72·9	
		E.	1·5	82	85	83½	49·7	

Diagrams showing changes of current at far end of line caused by the signals.

Vertical scale 1/100th of an inch = 1 division (strength of current).

Horizontal scale 1/10th of an inch = 1 second (time).

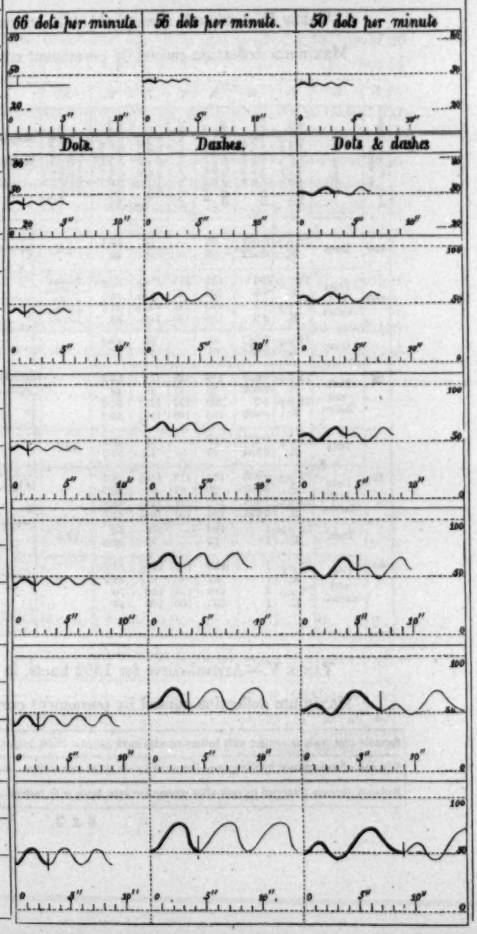

TABLE VII.—Arrival-curve for 1006 knots, in 4 coils. July 29, 1859.

Maximum deflection caused by permanent current from 72 p.p. ... 277[d].

Seconds after making contact with battery or with earth	1¼	1½	2	2½	3	3½	4½	4½	4½	6	7	9½	14½	19½
Division of scale passed by spot as current rises at far end of line	—	—	—	200	—	210	220	—	230	—	240	250	—	270
Division of scale passed by spot as current falls at far end of line	120	110	100	—	60	—	—	50	—	40	—	—	15	—
Distance on scale traversed by spot after contact has been made with battery or with earth	157	167	177	200	217	210	220	227	230	237	240	250	262	270
Reduced distance traversed by spot after contact has been made with battery or with earth	56·7	60·3	63·9	72·2	78·3	75·8	79·4	81·9	83	85·6	86·6	90·2	94·6	97·5

TABLE VIII.—Arrival-curve for 1165 knots, in 6 coils. July 29, 1859.

Maximum deflection caused by permanent current from 72 p.p. ... 264[d].

Seconds after making contact with battery or with earth	2½	3½	3½	4½	7	9	10	17	23
Division of scale passed by spot as the current rises at far end of line	—	200	—	220	—	240	—	—	260
Division of scale passed by spot as the current falls at far end of line	70	—	60	—	30	—	20	10	—
Distance on scale traversed by spot after contact has been made with battery or with earth	194	200	204	220	234	240	244	254	260
Reduced distance traversed by spot after contact has been made with battery or with earth	73·5	75·8	77·3	83·4	88·7	91	92·5	96·3	98·5

TABLE IX.—Signals through 1165 knots, in 6 coils. July 29, 1859.

Maximum deflection caused by permanent current from 72 p.p. ... 264[d].

Beats of metronome per minute.	Signals sent.	Source of electricity in contact with line at near coil.	Duration of contact at near end.	Limit of deflection at far end. First observation.	Second observation.	Mean limit of deflection caused by contact.	Reduced mean limit of deflection caused by contact.	Reduced mean amplitude of oscillation caused by two contacts.
100	Dots.	72 p.p.	0·6	130	125	127½	48·3	11·4
		E.	0·6	100	95	97½	36·9	
	Dashes.	72 p.p.	1·2	190	—	190	72	22·7
		E.	0·6	130	—	130	49·3	
	Dots and dashes.	72 p.p.	0·6	150	145	147½	55·9	
		E.	0·6	110	105	107½	40·7	
		72 p.p.	1·2	180	180	180	68·2	
		E.	0·6	120	120	120	45·5	
	A.	72 p.p.	0·6	115	—	115	43·6	
		E.	0·6	70	—	70	26·5	
		72 p.p.	1·2	170	—	170	64·4	
		E.	1·2	90	—	90	34·1	

Diagrams showing changes of current caused at far end of line by the signals.

Vertical scale $\frac{1}{100}$th of an inch = 1 division (strength of current).

Horizontal scale $\frac{1}{10}$th of an inch = 1 second (time).

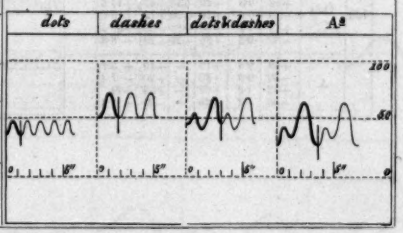

TABLE X.—Arrival-curve for 1165 knots, in 6 coils. July 29, 1859.

Maximum deflection caused by permanent current from +42 p.p. . . 157^d
" " " " " −30 p.p. . . 113^d
Sum of the two deflections . . . . . 270^d

Seconds after making contact with positive battery or with negative battery	3	4	4	4½	4½	7	9	9½	13	14	17	18	25
Division of scale passed by spot as the current arises at far end of line, after contact has been made with positive battery	+90	—	+100	+110	—	—	+130	—	—	+145	—	+150	+155
Division of scale passed by spot as the current falls at far end of line, after contact has been made with negative battery	—	−60	—	—	−70	−80	—	−90	−100	—	−105	—	—
Distance on scale traversed by spot after contact with either battery	203	217	213	223	227	237	243	247	257	258	262	263	268
Reduced distance traversed by spot after contact has been made with either battery	75·1	80·3	78·8	82·5	84	87·7	89·9	91·4	95·1	95·5	96·9	97·3	99·2

TABLE XI.—Signals through 1165 knots, in 6 coils, with alternate positive and negative currents. July 29, 1859.

Maximum deflection caused by permanent current from +42 p.p. . . . 157^d
" " " " " " " −30 p.p. . . . 113^d
Sum of two deflections . . . . . 270^d

Knots of micrometre per minute.	Signals sent.	Source of electricity in contact with line at near end.	Duration of contact at near end.	Limit of deflection at far end. First observation.	Second observation.	Mean limit of deflection caused by contact.	Reduced mean limit of deflection caused by contact.	Reduced mean amplitude of oscillation caused by two contacts.
100	Dots.	+42	0·6	+35	+32	+33½	+12·4	13
		−30	0·6	0	− 3	− 1½	− 0·6	
	Dashes.	+42	1·2	+95	+95	+95	+35·1	21·2
		−30	0·6	+40	+35	+37½	+13·9	
	Dots and dashes.	+42	0·6	+40	+55	+47½	+17·6	
		−30	0·6	+10	+20	+15	+ 5·6	
		+42	1·2	+80	+85	+82½	+30·5	
		−30	0·6	+20	+25	+22½	+ 8·3	
	A.	+42	0·6	+10	—	+10	+ 3·7	
		−30	0·6	−20	—	−20	− 7·4	
		+42	1·2	+65	—	+65	+24	
		−30	1·2	−20	—	−20	− 7·4	

Diagrams showing changes of current caused at far end of line by the signals.

Vertical scale $\frac{1}{100}$th of an inch = 1 division (strength of current).

Horizontal scale $\frac{1}{10}$th of an inch = 1 second (time).

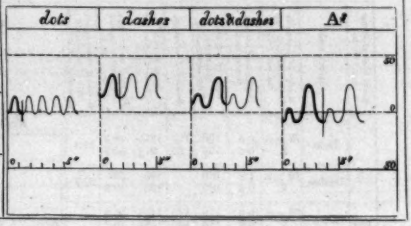

TABLE XII.—Arrival-curve for 2192 knots, in 10 coils. July 30, 1859.
Maximum deflection caused by permanent current from 72 p.p. ... 133[d].

Seconds after making contact with battery or with earth...	3″/4	4″	3″/4	4″	4″/4	5″	5″/2	6″	6″/4	7″	7″/2	8″/4	8″/4	9″	9″/2	10″/4	11″	13″/2	16″/2	17″	30″	50″
Division of scale passed by spot as the current rises at far end of line	30	40	50	60	—	—	80	—	90	95	100	105	—	110	110	115	—	120	125	125	130	131
Division of scale passed by spot as the current falls at far end of line	—	—	—	—	70	60	—	50	—	—	—	—	30	—	—	—	20	—	—	—	—	—
Distance on scale traversed by spot after contact has been made with battery or earth..	30	40	50	60	63	73	80	83	90	95	100	105	103	110	110	115	113	120	125	125	130	131
Reduced distance traversed by spot after contact has been made with battery or earth..	22·6	30·1	37·6	45·1	47·4	54·9	60·2	62·4	67·7	71·4	75·2	79	77·5	82·7	82·7	86·5	85	90·2	94	94	97·8	98·5

TABLE XIII.—Signals through 2192 knots, in 10 coils. July 30, 1859.
Maximum deflection caused by permanent current from 72 p.p. ... 133[d].

Beats of metronome per minute.	Signals sent.	Source of electricity in use at near end.	Duration of contact at near end.	Limit of deflection at far end. First observation.	Second observation.	Third observation.	Fourth observation.	Mean limit of deflection caused by contact.	Reduced mean limit of deflection caused by contact.	Reduced mean amplitude of oscillation caused by two contacts.
100	Dots.	72 p.p.	0″·6	57	—	—	—	57	42·9	0
		E.	0·6	57	—	—	—	57	42·9	
80	Dots.	72 p.p.	0·75	61	—	—	—	61	45·9	1·5
		E.	0·75	59	—	—	—	59	44·4	
60	Dots.	72 p.p.	1	64	—	—	—	64	48·1	3
		E.	1	60	—	—	—	60	45·1	
40	Dots.	72 p.p.	1·5	68	—	—	—	68	51·1	7·5
		E.	1·5	58	—	—	—	58	43·6	
36	Dots.	72 p.p.	1·666	68	70	—	—	69	51·9	9·4
		E.	1·666	55	58	—	—	56½	42·5	
	Dashes.	72 p.p.	2·333	95	96	—	—	95½	71·8	15·8
		E.	1·666	74	75	—	—	74½	56·0	
	Dots and dashes.	72 p.p.	1·666	76	80	75	80	77	57·9	
		E.	1·666	65	65	60	65	64	48·1	
		72 p.p.	3·333	90	90	89	92	90	67·6	
		E.	1·666	70	70	69	71	70	52·6	
	A.	72 p.p.	1·666	60	63	60	60	61	45·9	
		E.	1·666	50	53	51	51	51	38·4	
		72 p.p.	3·333	85	85	84	85	85	63·9	
		E.	3·333	45	47	45	46	46	34·6	
30	Dots.	72 p.p.	2	72	—	—	—	72	54·1	12·7
		E.	2	55	—	—	—	55	41·4	
	Dashes.	72 p.p.	4	100	—	—	—	100	75·2	22·6
		E.	2	70	—	—	—	70	52·6	
	Dots and dashes.	72 p.p.	2	79	78	80	—	79	59·2	
		E.	2	62	60	60	—	61	45·9	
		72 p.p.	4	95	94	95	—	95	71·4	
		E.	2	68	68	67	—	68	51·1	
	A.	72 p.p.	2	65	64	63	—	64	48·1	
		E.	2	50	50	50	—	50	37·6	
		72 p.p.	4	91	91	92	—	91	68·4	
		E.	4	41	42	42	—	42	31·6	
18	Dots.	72 p.p.	3·333	85	—	—	—	85	63·9	28·6
		E.	3·333	47	—	—	—	47	35·3	

Diagrams showing changes of current at far end of line caused by the signals.
Vertical scale $\frac{1}{100}$th of an inch = 1 division (strength of current).
Horizontal scale $\frac{1}{10}$th of an inch = 1 second (time).

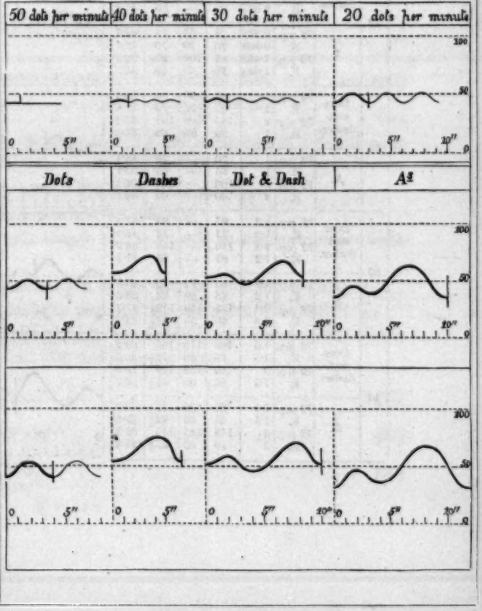

TABLE XIV.—Signals sent through 1812 knots, in 9 coils. July 30, 1859.

Maximum deflection caused by permanent current from 72 p.p. ... 166[d].

Beats of metronome per minute.	Signals sent.	Source of electricity in circuit with line at each end.	Duration of contact at each end.	Limit of deflection caused by. First observation.	Second observation.	Mean limit of deflection caused by contact.	Reduced mean limit of deflection caused by contact.
92	Dots and dashes.	72 p.p.	0·652	88	90	89	53·6
		E.	0·652	83	83	83	50
		72 p.p.	1·304	95	95	95	57·2
		E.	0·652	88	90	89	53·6
	A.	72 p.p.	0·652	66	—	66	39·7
		E.	0·652	65	—	65	39·1
		72 p.p.	1·304	85	—	85	51·2
		E.	1·304	65	—	65	39·1
84	Dots and dashes.	72 p.p.	0·714	91	—	91	54·8
		E.	0·714	85	—	85	51·2
		72 p.p.	1·429	100	—	100	60·2
		E.	0·714	90	—	90	54·2
	A.	72 p.p.	0·714	72	—	72	43·3
		E.	0·714	70	—	70	42·1
		72 p.p.	1·429	90	—	90	54·2
		E.	1·429	70	—	70	42·1
72	Dots and dashes.	72 p.p.	0·833	92	—	92	55·4
		E.	0·833	80	—	80	48·2
		72 p.p.	1·666	100	—	100	60·2
		E.	0·833	90	—	90	54·2
	A.	72 p.p.	0·833	75	75	75	45·1
		E.	0·833	70	70	70	42·1
		72 p.p.	1·666	95	100	97½	58·7
		E.	1·666	70	68	69	41·5
60	Dots and dashes.	72 p.p.	1	95	93	94	56·6
		E.	1	80	78	79	47·6
		72 p.p.	2	105	105	105	63·2
		E.	1	90	90	90	54·2
	A.	72 p.p.	1	70	—	70	42·1
		E.	1	65	—	65	39·1
		72 p.p.	2	100	—	100	60·2
		E.	2	60	—	60	36·1
50	Dots and dashes.	72 p.p.	1·2	95	—	95	57·2
		E.	1·2	75	—	75	45·1
		72 p.p.	2·4	110	—	110	66·2
		E.	1·2	85	—	85	51·2
	A.	72 p.p.	1·2	80	72	76	45·8
		E.	1·2	68	60	64	38·6
		72 p.p.	2·4	115	110	112½	67·7
		E.	2·4	60	55	57½	34·6
40	Dots and dashes.	72 p.p.	1·5	100	110	105	63·2
		E.	1·5	75	80	77½	46·7
		72 p.p.	3	130	130	125	75·3
		E.	1·5	85	90	87½	52·7
	A.	72 p.p.	1·5	80	75	77½	46·7
		E.	1·5	65	60	62½	37·6
		72 p.p.	3	115	115	115	69·3
		E.	3	50	45	47½	28·6

Diagrams showing changes of current caused at far end of line by the signals.

Vertical scale $\frac{1}{100}$th of an inch = 1 division (strength of current).

Horizontal scale $\frac{1}{10}$th of an inch = 1 second (time).

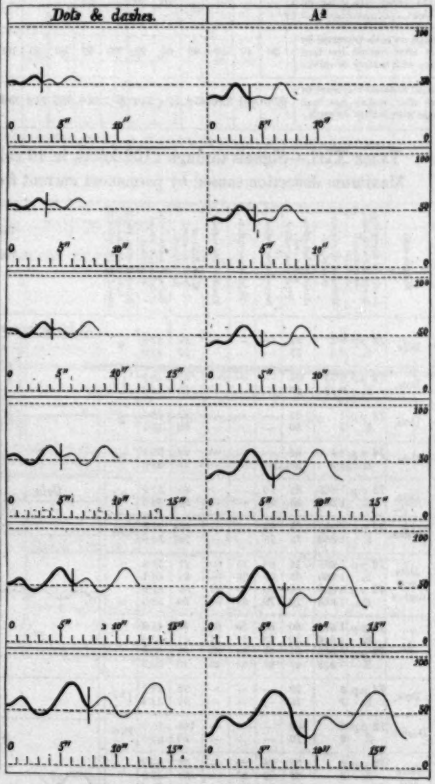

TABLE XV.—Speeds and Amplitudes for various lengths.

	1. Number of beats per minute = N.	2. Observed amplitude reduced to percentage.	3. Product of number of beats into square of length $= N \times L^2$.	4. Product of number of beats into square of length corrected for battery and galvanometer $= N \times (L+160)^2$.
L=1500...	130	2·5	297 × 10⁶	364 × 10⁶
	92	5	207 „	254 „
	73	10	162 „	198 „
	60	12·5	135 „	165 „
L=1802...	132	0	429 × 10⁶	508 × 10⁶
	112	1·2	364 „	431 „
	100	1·8	325 „	385 „
	92	2·7	299 „	354 „
	84	3	273 „	323 „
	72	3·9	234 „	277 „
	60	5·9	195 „	231 „
	50	9·2	162 „	192 „
	40	14·8	130 „	154 „
L=2192...	100	0	480 × 10⁶	553 × 10⁶
	80	1·5	384 „	443 „
	60	3	288 „	332 „
	40	7·5	192 „	221 „
	36	9·4	173 „	199 „
	30	12·7	144 „	166 „
	18	23·6	86 „	100 „

APPENDIX.

Received January 14, 1863.

SECTION I.—*Effect of conduction across the sheath of an insulated wire, or of uniformly imperfect insulation on the permanent received current.*

The author is indebted to Professor W. THOMSON for the substance of the following theory.

Consider a cable extending infinitely in one direction from an origin O.

Let the distance of any point P from the origin be called x.

Let i denote the resistance of the unit length of the sheath to conduction across it, *i. e.* the measure of the insulation.

Let m denote the resistance of the unit length of the wire to conduction along it.

Let the potential at O be called V, and the potential at any point P be called V_x.

Let the strength of the current entering at O be called Q, and the strength of the current at P be called Q_x. Then it is not difficult to prove that

$$Q_x = Q\, \epsilon^{-x\sqrt{\frac{m}{i}}}, \quad \ldots \quad (1.)$$

$$V_x = V\, \epsilon^{-x\sqrt{\frac{m}{i}}}, \quad \ldots \quad (2.)$$

$$Q = \frac{V}{(im)^{\frac{1}{2}}}. \quad \ldots \quad (3.)$$

We can pass from this case to that of a finite cable of the length l with one end in connexion with the earth by the device of electrical images.

Superimpose two potential curves satisfying equation (2.) with equal but opposite potentials $+V$ and $-V$ at their origins O and O_1. Let these points be situated at a distance $2l$ apart, and let the curves extend from their origin to meet and cross one another. The resultant potential will necessarily be zero halfway between O and O_1, and the resultant curve between this point and each origin will represent the variation of potentials in a cable of the length l with one end in connexion with the earth and the origin at a certain positive or negative potential.

By putting these results into a mathematical form, we obtain from equations (1.) and (2.),

$$V_x = V\left(\epsilon^{-x\sqrt{\frac{m}{i}}} - \epsilon^{-(2l-x)\sqrt{\frac{m}{i}}}\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4.)$$

$$Q_x = Q\left(\epsilon^{-x\sqrt{\frac{m}{i}}} + \epsilon^{-(2l-x)\sqrt{\frac{m}{i}}}\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5.)$$

But V and Q do not represent the potential and current at the origin of the finite cable, but the potential and current at the origin of the hypothetical infinite curves superimposed. In order to obtain V_x and Q_x in function of any given potential V_0 at the origin of the finite cable, we must obtain the value of V in function of V_0 by putting $x=0$ in equation (4.), and substitute the value of V in function of V_0 in the general equations (4.) and (5.).

Then we have

$$V_0 = V\left(1 - \epsilon^{-2l\sqrt{\frac{m}{i}}}\right),$$

and hence

$$V_x = V_0 \frac{\epsilon^{-x\sqrt{\frac{m}{i}}} - \epsilon^{-(2l-x)\sqrt{\frac{m}{i}}}}{1 - \epsilon^{-2l\sqrt{\frac{m}{i}}}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6.)$$

and

$$Q_x = \frac{V_0}{(im)^{\frac{1}{2}}} \frac{\epsilon^{-x\sqrt{\frac{m}{i}}} + \epsilon^{-(2l-x)\sqrt{\frac{m}{i}}}}{1 - \epsilon^{-2l\sqrt{\frac{m}{i}}}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7.)$$

To obtain the current flowing into the cable at its origin, make $x=0$; then

$$Q_0 = \frac{V_0}{(im)^{\frac{1}{2}}} \frac{1 + \epsilon^{-2l\sqrt{\frac{m}{i}}}}{1 - \epsilon^{-2l\sqrt{\frac{m}{i}}}}$$

and

$$Q_x = Q_0 \frac{\epsilon^{-x\sqrt{\frac{m}{i}}} - \epsilon^{-(2l-x)\sqrt{\frac{m}{i}}}}{1 + \epsilon^{-2l\sqrt{\frac{m}{i}}}};$$

or, for brevity, writing $\theta = l\sqrt{\frac{m}{i}}$ and $\theta_l = (l-x)\sqrt{\frac{m}{i}}$,

$$Q_0 = \frac{V_0}{lm} \frac{\theta(\epsilon^{\theta} + \epsilon^{-\theta})}{(\epsilon^{\theta} - \epsilon^{-\theta})}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8.)$$

and

$$Q_x = Q_0 \frac{\epsilon^{\theta_l} + \epsilon^{-\theta_l}}{\epsilon^{\theta} + \epsilon^{-\theta}}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9.)$$

When $x=l$,

$$Q_l=Q_0\frac{2}{\epsilon^{\beta}+\epsilon^{-\beta}}. \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (10.)$$

The equations (8.) and (10.), applied to the case of the Red Sea cable, give the results in the text,

$$l=2192, \ldots m=250\times10^6 \ldots i=228\times10^{13},$$

$$\epsilon^{\beta}=\epsilon^{0\cdot7258}=2\cdot0664 \ldots \epsilon^{-\beta}=0\cdot48394,$$

$$Q_0=1\cdot1694\frac{V_0}{lm}=\text{the entering current},$$

$$Q_l=0\cdot784Q_0=0\cdot9168\frac{V_0}{lm}.$$

Similarly, when $i=289\times10^{13}$,

$$Q_l=0\cdot824Q_0=0\cdot938\frac{V_0}{lm}.$$

If the cable were perfectly insulated, by OHM's law,

$$Q_l=\frac{V_0}{lm}.$$

SECTION II.—TABLE XVI.

1.	2.	3.	4.	5.	6.
Period of dot in seconds in function of a.	Factor used in the formula given in the third column.	Reciprocal of amplitude of variation in the received current produced by harmonic variation of potential at the operating end.	Reciprocal of amplitude of variation in the received current produced by the dot signal.	Amplitude produced by dot signals.	Number of dots per minute.
θ in function of a. $a=\frac{ckp}{\epsilon^{\beta}}\times\log_{\epsilon}\left(10^{\frac{1}{10}}\right)$.	$i=\sqrt{\frac{\theta}{a}}\times\sqrt{\frac{\epsilon^{\beta}}{\left(\log_{\epsilon}\frac{1}{\sigma}\right)^2}}$ $\sigma=10^{\frac{1}{10}}$.	$\left\{2\sqrt{2}.i\log_{\epsilon}\left(\frac{1}{\sigma}\right)\epsilon^{\beta}\right\}^{-1}$.	Third column multiplied into $\frac{\pi}{4}$.	Reciprocal of fourth column multiplied by 100.	$\frac{60}{\theta}$.
$0\cdot25\times a$	100·7926	182,840,000	143,600,000	0·000,000,696	$240\times\frac{1}{a}$
0·5 „	71·2711	288,070	226,250	0·000,442	200 „
0·75 „	58·1926	17,402	13,668	0·007,315	80 „
1·0 „	50·3963	3,337·9	2,631·5	0·038,00	60 „
1·1 „	48·0510	2,040·0	1,602·2	0·062,42	54·5 „
1·2 „	46·0053	1,330·3	1,044·8	0·095,7	50·0 „
1·3 „	44·2005	913·82	717·71	0·139,3	46·2 „
1·4 „	42·5926	654·97	514·41	0·194,5	42·9 „
1·5 „	41·1496	486·24	381·89	0·261,8	40·0 „
1·6 „	39·8418	371·60	291·86	0·342,6	37·5 „
1·7 „	38·6522	291·26	228·76	0·437,1	35·3 „
1·8 „	37·5632	233·24	182·40	0·548,2	33·3 „
1·9 „	36·5617	190·28	149·44	0·669,3	31·6 „
2·0 „	35·6356	157·73	123·88	0·807,1	30·0 „
2·1 „	34·7777	132·65	104·17	0·959,7	28·6 „
2·2 „	33·9782	112·90	88·67	1·127,8	27·3 „
2·3 „	33·2299	97·21	76·35	1·309,8	26·1 „
2·4 „	32·5305	84·52	66·38	1·506,5	25·0 „
2·5 „	31·8742	74·17	58·25	1·716,7	24·0 „
2·6 „	31·2535	65·57	51·50	1·941,7	23·1 „
2·7 „	30·6696	58·41	45·88	2·179,6	22·2 „
2·8 „	30·1180	52·39	41·15	2·430,1	21·4 „

TABLE XVI. (continued).

1.	2.	3.	4.	5.	6.
Period of dot in seconds in function of a.	Factor used in the formula given in the third column.	Reciprocal of amplitude of variation in the received current produced by harmonic variation of potential at the operating end.	Reciprocal of amplitude of variation in the received current produced by the dot signal.	Amplitude produced by dot signals.	Number of dots per minute.
θ in function of a. $a=\frac{ekP}{\sigma^2}\times\log_e\left(10^{\frac{1}{10}}\right)$.	$i=\sqrt{\frac{\theta}{a}}\times\sqrt{\frac{\sigma^2}{\left(\log\frac{1}{\epsilon_0}\right)^3}}$ $\epsilon=10^{\frac{1}{10}}$.	$\left\{2\sqrt{2}.i\log_e\left(\frac{1}{\epsilon}\right)e^i\right\}^{-1}$.	Third column multiplied into $\frac{\pi}{4}$	Reciprocal of fourth column multiplied by 100.	$\frac{60}{\theta}$
$2{\cdot}9\times a$	29·5944	47·26	37·12	2·694,0	$20{\cdot}7\times\frac{1}{a}$
3·0 "	29·0964	42·86	33·66	2·970,9	20·0 "
3·1 "	28·6232	39·07	30·69	3·195,9	19·4 "
3·2 "	28·1724	35·78	28·10	3·558,7	18·7 "
3·3 "	27·7422	32·91	25·85	3·868,5	18·2 "
3·4 "	27·3312	30·39	23·87	4·189,4	17·6 "
3·5 "	26·9380	28·16	22·12	4·520,8	17·1 "
3·6 "	26·5612	26·19	20·57	4·861,5	16·7 "
3·7 "	26·1998	24·43	19·19	5·211,0	16·2 "
3·8 "	25·8528	22·86	17·53	5·704	15·8 "
3·9 "	25·5192	21·44	16·84	5·938	15·4 "
4·0 "	25·1981	20·17	15·84	6·313	15·0 "
4·1 "	24·8900	19·02	14·94	6·693	14·6 "
4·2 "	24·5909	17·97	14·11	7·087	14·3 "
4·3 "	24·3033	17·02	13·37	7·479	14·0 "
4·4 "	24·0255	16·15	12·68	7·886	13·6 "
4·5 "	23·7570	15·35	12·06	8·292	13·3 "
4·6 "	23·4974	14·62	11·48	8·711	13·0 "
4·7 "	23·2461	13·95	10·96	9·124	12·8 "
4·8 "	23·0021	13·33	10·47	9·551	12·5 "
4·9 "	22·7667	12·75	10·01	9·990	12·2 "
5·0 "	22·5379	12·22	9·60	10·417	12·0 "
5·1 "	22·3158	11·73	9·21	10·858	11·8 "
5·2 "	22·1002	11·27	8·85	11·299	11·5 "
5·3 "	21·8907	10·84	8·51	11·751	11·3 "
5·4 "	21·6871	10·44	8·20	12·195	11·1 "
5·5 "	21·4890	10·07	7·91	12·642	10·9 "
5·6 "	21·2963	9·72	7·634	13·099	10·7 "
5·7 "	21·1087	9·39	7·375	13·559	10·5 "
5·8 "	20·9259	9·08	7·131	14·023	10·4 "
5·9 "	20·7478	8·79	6·904	14·484	10·2 "
6·0 "	20·5742	8·52	6·732	14·854	10·0 "
6·1 "	20·4049	8·260	6·487	15·415	9·8 "
6·2 "	20·2396	8·017	6·296	15·883	9·66 "
6·3 "	20·0784	7·786	6·115	16·353	9·52 "
6·4 "	19·9209	7·569	5·944	16·824	9·37 "
6·5 "	19·7670	7·362	5·782	17·295	9·23 "
6·6 "	19·6167	7·166	5·628	17·590	9·09 "
6·7 "	19·4698	6·980	5·482	18·241	8·96 "
6·8 "	19·3261	6·803	5·443	18·372	8·82 "
6·9 "	19·1855	6·635	5·211	19·190	8·69 "
7·0 "	19·0480	6·474	5·085	19·666	8·57 "
7·1 "	18·9136	6·322	4·965	20·141	8·45 "
7·2 "	18·7817	6·176	4·851	20·614	8·33 "
7·3 "	18·6525	6·036	4·701	21·272	8·22 "
7·4 "	18·5260	5·903	4·636	21·575	8·11 "
7·5 "	18·4021	5·775	4·536	22·046	8·00 "
7·6 "	18·2807	5·652	4·439	22·528	7·90 "
7·7 "	18·1616	5·537	4·349	22·994	7·80 "
7·8 "	18·0448	5·425	4·260	23·474	7·69 "
7·9 "	17·9302	5·317	4·176	23·946	7·60 "
8·0 "	17·8178	5·214	4·095	24·420	7·50 "
9·0 "	16·7988	4·374	3·435	29·112	6·67 "
10·0 "	15·9367	3·780	2·969	33·681	6·00 "

Explanation of TABLE XVI.

Table XVI., given to the author by Professor W. THOMSON, will now be shortly explained. The author will not enter into any detailed explanation of the theory by which the results contained in the Table were obtained, as these results are the direct mathematical consequences of the equations given in the papers already alluded to, and as Professor THOMSON will probably himself publish the full mathematical development of the theory.

The first column headed Θ contains a series of "times" occupied by the full periods of electric operations, each of which, when continually repeated, produces a succession of equal and similar rises and falls in the received current, or of "dots" as they have been hitherto called in this paper. The series begins with the shorter and ends with the longer times, or, in other words, begins with the more rapid and ends with the slower speeds. The numbers in the first column are numbers measuring the times of the periods in terms of a certain quantity α taken as unity. The actual time in seconds occupied by each period or cycle of electric operations corresponding to the series in the first column is equal to the numbers entered there multiplied into α. This quantity α is equal to $\frac{ckl^2}{\pi^2} \cdot \log. \left(10^{\frac{1}{10}}\right)$, where

c = the electrostatical capacity of the insulated wire per unit of length in absolute electrostatic measure;

k = the resistance of the conductor per unit of length in absolute electrostatic measure;

l = the length of the conductor.

α varies therefore for every cable and for every length of the same cable. The meaning of this quantity will be best explained by the following extract from a letter of Professor THOMSON's to the author:—

"α, in definite absolute measure, means the tenth part of the time in seconds in which a simple harmonic electrification established in the wire and left to itself (two ends to earth) would subside to $\frac{1}{10}$th of its amount. Thus in the time α, an harmonic electrification subsides to $\frac{1}{10^{\frac{1}{10}}}$ of its amount. The subsidence here spoken of is the gradual loss of charge by conduction out through the ends to earth."

Now let the electrical operation producing the dot be a simple harmonic variation of the potential at one end while the other is connected to earth $\left(i.\,e.\text{ let } V = A \sin \frac{2\pi t}{\Theta}\text{, where } V = \text{the varying potential, } A = \text{a constant, and } \frac{t}{\Theta} = \text{any function of the whole period}\right)$. Then, measured as a fraction of the maximum current which would be received if the maximum potential A were constantly maintained at the sending end of the cable, the difference between the maximum and minimum received current will be the reciprocal of the number entered in the third column; or translating this into the language used in

the paper, the reciprocals of the numbers in the third column give the amplitude of the dot measured as a function of the maximum permanent current*. For instance, if each dot occupied a period α, the amplitude of variation in the received current would be $\frac{1}{3333}$th of the maximum permanent current, or would be 0·02956 per cent. of that current.

The fourth column is obtained by multiplying the numbers in the third column into a constant $\frac{\pi}{4}$. The numbers so obtained express the reciprocals of the amplitudes which would result if, instead of being subjected to the harmonic variation previously described, the end operated on had been maintained at the maximum potential for the first half of the periods Θ, and at the minimum during the second half. This was precisely the condition fulfilled when dots were sent in the experiments described. The potential of one pole of the battery was maintained at the sending end of the cable during one half of each dot, and the potential of the earth was maintained during the other half.

The fifth column contains the product of the reciprocals of the numbers in the fourth column multiplied into 100, and gives therefore the amplitudes produced by dots made as in the experiments occupying the various periods in the first column, and these amplitudes are moreover expressed in percentages of the maximum received current, as in the rest of the paper.

The product of the reciprocals of the times entered in the first column, multiplied into 60, will give a series of numbers corresponding to the number of dots per minute in terms of α. This series, expressing "speeds," is entered in the sixth column.

The numbers in the fifth and sixth columns used as coordinates give the curve, shown in fig. 11, Plate LI., corresponding most accurately with the observed speeds and amplitudes.

The scale of amplitudes, shown in full lines, corresponds to the numbers in the fifth column, and the scale of times, shown by dotted lines, corresponds to the values of $\frac{60}{\Theta}$ when α is taken as unity.

When in any case the amplitude corresponding to a given number of dots is known, the actual value of α can at once be determined from this curve. Thus observation (Table IV.) showed that for a length of 1500 knots of cable +160 knots of resistance, with 92 beats or 46 dots per minute, the amplitude was 5 per cent., and by the curve we find that this amplitude corresponded to a speed of $16{\cdot}4\times\frac{1}{\alpha}$; hence $46=16{\cdot}4\times\frac{1}{\alpha}$, or $\alpha=0''{\cdot}3565$†. From this value the electrostatical capacity per unit of length, and the specific inductive capacity of the dielectric could be determined. These points will, however, be more fully treated of in the second part of this paper.

* The second column only contains the value of a certain quantity i used in the formula by which the third column is calculated.

† It should be observed that inasmuch as this observation does not exactly fall on the curve, so the value of α differs a little from that which would be calculated by the curve alone, as presently to be described.

Quite similarly, if α be known, the number of beats per minute corresponding to any amplitude could be determined; but, practically, α need not enter into the calculation when treating of any given cable. The speed, amplitude, and length are here the three elements of every problem, and when two of these are known the third can be determined; but here it may be observed, that as the speed, multiplied into α, is constant for each amplitude, so will the speed, multiplied into the square of the length, be constant for each amplitude, and the scale of abscissæ may be so chosen as for any one cable to give directly this product by simple inspection.

It is this scale for the Red Sea cable which is drawn at the foot of the curve, fig. 11, and which enables the number of dots corresponding to every amplitude to be ascertained directly, and it is by this scale that the dots, crosses, or circles from Table XV. are put on the figure.

When, as in the present paper, the speed is taken as twice the number of dots, and the unit length is one knot, the ratio of the two scales must clearly be such that if

d = the number of divisions in the upper scale,

D = the corresponding number on the lower scale,

L = the length in knots,

then
$$\alpha = \frac{2dL^2}{D}.$$

Thus, taking a length of 1000 knots and a speed of 100 dots per minute, $D = 2 \times 10^6$, $d = 12{\cdot}6$, and hence $\alpha = 0{\cdot}126$; and the same value would be obtained whatever number of dots had been chosen.

This may be looked on as the mean value of α determined from twenty observations, since this ratio of the scales brought all the various circles, crosses, and stars into the closest approximation with the curve. The values of α for any other length are inversely proportional to the square of the lengths.

The algebraic headings of the different columns will allow them to be still further extended by those who may require to use the Table, as they virtually contain the equation of the curve.

XXXIX. *The Lignites and Clays of Bovey Tracey, Devonshire.*

By WILLIAM PENGELLY, *F.G.S. Communicated by Sir* CHARLES LYELL, *F.R.S.*

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THE little town or village of Bovey Tracey, in Devonshire, nestles at the foot of Dartmoor, very near its north-eastern extremity; it is situated on the left bank of the river Bovey, about two miles and a half above the point at which it falls into the Teign, and is about eleven miles from each of the towns Exeter, Torquay, and Totnes*,—bearing south-westerly from the first, north-westerly from the second, and northerly from the last.

A considerable plain stretches away from it in a south-easterly direction, having a length of six miles from a point about a mile west of Bovey to another nearly as far east of Newton; its greatest breadth, from Chudleigh Bridge on the north-east to Blackpool on the south-west, is four miles. It forms a lake-like expansion of the valleys of the Teign and Bovey rivers, especially the latter, whose course it may be said to follow in the higher part, where it is most fully developed; whilst the Teign constitutes its axis below the junction of the two streams. Its upper, or north-western portion, immediately adjacent to the village, is known as "Bovey Heathfield," and measures about 700 acres.

On its west and north-west, rise the lofty granite hills of Dartmoor, with their border of metamorphic rocks; on the north, the trappean elevations of Hennock; on the north-east and east, the Greensands of the Haldons, and the traps and limestones of the Chudleigh and Kingsteignton districts; and on the south, the traps, Devonian limestones, and associated rocks extending from Newton towards Ashburton†.

Contrasted with this rugged and elevated country, the so-called "plain" is not without some claim to the appellation, though by no means characterized by evenness of surface.

Shafts and other excavations have shown that the deposits in this basin consist of an accumulation of coarse gravel (mixed with sand and clay), of variable thickness, unconformably covering distinct strata of lignite, clay, and sand, which are familiar to geologists as the "Bovey deposit," whilst the lignite is equally well known as "Bovey coal."

This deposit not only occupies the plain which has been described, but is continued, in a narrow southerly prolongation, from Newton to near Kingskerswill, about three and a half miles from Torbay. This entire prolongation is a divergence from the Teign. Where it crosses the estuary of that river it is about four miles from the coast.

The most important of the excavations is that known as the "Coal-pit," which is situated on the Heathfield, somewhat less than a mile south of the village, and about the same distance from the western margin of the deposit. It is open to the day, and

* The distances throughout are measured in straight lines on the Ordnance Maps.

† See Map, Plate LII.

is, in form, a rude parallelogram, having its longest side, about 960 feet, in the direction from S. 75° E. to N. 75° W., whilst the shortest measures 340 feet, and has a bearing of N. 35° E. to S. 35° W.* Its greatest depth, at the western end, is nearly 100 feet.

Subterranean excavations have been carried on very extensively, in various directions, by means of tunnels opening out of the pit at its bottom. At present the working is confined to one tunnel, extending 190 fathoms, almost in a straight line, in the direction N. 65° W. from the western end of the pit.

The lignite was formerly used in large quantities in an adjoining pottery; at present but little is employed there, and its use is almost entirely confined to the poorer cottagers of the immediate district. A very offensive sulphurous smell, which it emits during combustion, prevents its general domestic use.

The refuse matter, consisting of clay and waste or valueless lignite, is lodged on the surface around the pit. Iron-pyrites occurs in it in considerable quantities; and spontaneous combustion is common in fresh refuse, especially after much rain. The fire is not generally visible near the surface in the day-time, but its presence is indicated by smoke and the very offensive odour previously mentioned. Cracks, having their sides lined with flowers of sulphur, cross the burning mass in various directions. Occasionally, crystals of sulphate of alumina are also formed.

The attention of both the scientific and the commercial world has long been called to this deposit; several accounts of it have been laid before various learned societies, and otherwise given to the world†. Many of these, besides descriptions of the characters

* The bearings are in all cases magnetic when expressed, as above, with an appearance of numerical exactness.

† The following is a list of the principal writers on the Bovey beds:—

Rev. Dr. Jeremiah Milles, in the Philosophical Transactions, vol. li. Part II. p. 534, &c., in 1760.

Mr. Kirwan, in his 'Elements of Mineralogy,' vol. ii. p. 60, &c., published in 1794.

Dr. Maton, in his 'Observations on the Western Counties of England,' made in the years 1794 and 1796, vol. i. p. 106, &c.

Mr. Hatchett, in the Transactions of the Linnean Society, vol. iv. p. 129, &c., in 1797.

Mr. Brice, in his 'History and Description, Ancient and Modern, of the City of Exeter,' p. 141, &c., published in 1802.

Mr. Parkinson and Mr. Scammell, in Parkinson's 'Organic Remains,' vol. i. p. 104, &c., in 1804.

Mr. Hatchett, in the Philosophical Transactions, vol. for 1804, Part I. p. 396, &c.

Mr. Vancouver, in his 'Agriculture of the County of Devon,' p. 70, &c., published in 1808.

Dr. J. M'Culloch, in the Transactions of the Geological Society, 1st Series, vol. ii. p. 1, &c., in 1814.

Rev. D. Lysons, in 'Magna Britannica,' vol. vi., "Devonshire," p. ccxlix, published in 1822.

Rev. W. D. Conybeare and Mr. W. Phillips, in the 'Outlines of the Geology of England and Wales,' pp. 328 and 364, published in 1822.

Mr. Kingston, in the 'Teignmouth Guide,' vol. ii., published about 1832 or 1833.

Mr. Godwin-Austen, in the Transactions of the Geological Society, 2nd Series, vol. vi. part 2, p. 439, &c., in 1834, and subsequently.

Sir H. De la Beche, in his 'Report of Cornwall, Devon, &c.' pp. 248, 255, 515, &c., in 1839.

Mr. F. Vaux, in Quart. Journ. Chem. Soc., London, vol. i. p. 318, &c., in 1849.

Dr. Hooker, in Quart. Journ. Geol. Soc. vol. xi. p. 506, &c., in 1855.

Dr. Croker, in Quart. Journ. Geol. Soc. vol. xii. p. 354, in 1856.

and arrangement of the strata, contain speculations and discussions on various topics, especially the mineral or vegetable origin of the lignite, the mode in which the materials of the deposit were accumulated, and the place of the formation in the chronological series of the geologist. These may be said to have resulted in a settled conviction that the lignite is of vegetable origin, that the clays and sands had been furnished by the disintegration of the Dartmoor granite, and that the whole is of supracretaceous age—and a general belief that the plants had not grown on, but had been transported to, the area they now occupy. The exact chronology of the formation was by no means agreed on, further than that there seemed to be a prevalent but vague opinion that, geologically speaking, it was very modern. The only definite expression that had been given on the question was the provisional one that the deposit belonged to the Post-pliocene epoch; this was based on a cone said to have been found in one of the uppermost beds of lignite, and which was identified by Dr. Hooker as belonging to the Scotch fir (*Pinus sylvestris*)*. This and some small seed-vessels, described by Dr. Hooker under the name of *Folliculites minutulus*, were the only identifiable fossils which, prior to the late explorations, had been found at Bovey. Indeed, so recently as 1839, Sir H. De la Beche stated that, "excepting the lignite itself, *no* organic remains had been found in the deposit"†. Many geologists, however, were unwilling to accept this chronology as conclusive, nor were they without hopes that, on a careful and thorough examination being made, the beds might be found to contain fuller and more reliable evidence on the question.

During the spring of 1860, Dr. Falconer made several visits to Bovey and various localities in its neighbourhood where clay-works were, or had been, carried on. The result was a strong impression that the deposit would be found to belong to the Miocene period. In one of these visits he was accompanied by the Rev. R. Everest, F.G.S., and in another by Sir C. Lyell, when they had an opportunity of examining the large collection of specimens of the lignite made by the late Dr. Croker. Soon afterwards Dr. Falconer introduced the subject to Miss Burdett Coutts as one which, for the credit of British geology, it was eminently desirable to have very fully investigated. After a visit to the Bovey "Coal-pit," Miss Coutts, with characteristic liberality, furnished me with means to undertake the work. I received the most prompt and cordial co-operation from the proprietor, John Divett, Esq., and was so fortunate as to secure the services of Mr. H. Keeping, the well-known fossil-collector, of the Isle of Wight.

The lignite-beds, having suffered less from the weather than the interstratified clays and sand, stand out in relief, like a series of rude mouldings, on the wall of the pit, especially on its southern side; so that it is not difficult to make out, in a rough way, the succession of the beds. Nevertheless the clay and sand have been so much washed over the surface of the wall that it is impossible to do more than this; hence it was decided to make a fresh section—in fact, to cut a series of steps, on a large scale, by which to descend the face of the artificial cliff from top to bottom, and thereby accomplish the double work of collecting fossils and disclosing the geology of the deposit.

* Quart. Journ. Geol. Soc. vol. xi. p. 566, &c. † Report of Cornwall, Devon, &c., p. 257.

As we descended, the thickness of each bed and the amount and direction of its *dip* were carefully measured; a sample, and when necessary more than one, of every bed was taken, each in a separate box, and every important fact, as to the character of the bed and the occurrence or not of fossils in it, was carefully noted. The mean of the several measurements, all very near the average, gave a *dip* of 12½° towards S. 35° W. (magn.).

The results of this systematic exploration are exhibited below.

Section 1, *of the Bovey Deposit, in the south wall of the "Coal-pit," near its western end. Dip* 12½° *towards S.* 35° *W.* (*magn.*).

Beds.	Thickness. ft.	in.	Totals. ft.	in.	
1	7	6	7	6	Sandy Clay.—Contains a large number of angular and subangular stones, without anything like regularity in their arrangement. This is locally termed "The Head." The upper two inches is a peaty soil, also containing stones.
2	2	6	10	0	Clay.—Plastic. Contains a few fragments of lignite. The uppermost four and the lowest two inches are of a buff colour; the middle band dark, approaching to black.
3	6	3	16	3	Sand.—Quartzose, with a ferruginous clay at the base.
4	2	9	19	0	Clay.—The uppermost ten inches more or less dark, sometimes approaching to black, in colour.
5		7	19	7	Lignite.—Woody and brittle.
6		11	20	6	Clay.—Very dark. Contains much broken lignite.
7	1	3	21	9	Lignite.—In some places woody, in others a mass of *Sequoia Couttsiæ*, Heer, and fern débris.
8		5	22	2	Clay.—Dark. Some broken lignite. Graduates into sand at the base.
9	2	0	24	2	Sand.
10	2	0	26	2	Clay.—Tough. Light lead-colour. Contains lenticular patches of sand, and, at the base, much fragmentary lignite.
11		8	26	10	Sand.—Sometimes ferruginous; in some cases cemented into a coarse grit or very fine conglomerate.
12	2	6	29	4	Clay.—Light lead-colour in the upper part, darker towards the base. Contains fragments of lignite.
13	1	0	30	4	Lignite.—Woody, loose, very brittle. The bed ill-defined, graduating into clay at each surface.
14	2	9	33	1	Clay.—Sandy and brittle. Contains a few fragments of lignite near the base. The uppermost and lowest parts of the bed are dark, the middle lighter, in colour.
15		7	33	8	Lignite.—Woody, loose, and brittle.
16	4	0	37	8	Clay.—Rather light in colour towards the top. Contains two bands of almost continuous broken lignite, one twelve, the other thirty inches above the base, the uppermost being the least persistent. The clay is not laminated; it breaks into irregular-shaped fragments, generally quite angular and with plane faces.
17	1	5	39	1	Lignite.—The lowest part of this bed abounds, in some places, with dicotyledonous leaves; where they do not occur, the lignite is very woody.
18	2	9	41	10	Clay.—Not laminated. Light in colour. Contains fragments of lignite.

Beds.	Thickness. ft.	in.	Totals. ft.	in.	
19	2	1	43	11	Lignite.—Contains much clay in almost continuous bands.
20	1	2	45	1	Clay.—Laminated. Brittle. Rich in fragments of lignite.
21	3	4	48	5	Lignite.—Hard. Brittle. Broken. Contains a few seeds.
22	2	0	50	5	Clay.—Dark. Rather brittle. Coarsely laminated.
23	1	0	51	5	Lignite.—Contains much clay.
24	1	0	52	5	Clay.—Dark. Brittle. Contains a few portions of lignite.
25	6	2	58	7	Lignite.—Contains patches of dark clay. Seeds, flat in form, occur in the uppermost portion. The base is commonly a mass of large leaf-like forms and fronds of ferns; the former are Dr. Croker's "flabelliform leaves"*.
26	2	1	60	8	Clay.—Light drab colour. Extremely rich in fossil stems, leaves, and fruits of *Sequoia Couttsiæ*, seeds of various kinds, and dicotyledonous leaves. An almost continuous band of broken lignite occurs at the base of the bed.
27	11	1	71	9	Sand.—Quartzose. Very coarse in the uppermost part, but becomes gradually finer towards the base. Contains somewhat large lenticular patches of clay. Ferruginous stains and bands are common.
28	5	9	77	6	Clay.—Light colour. Near the top it is somewhat sandy.
29	3	2	80	8	Clay.—Dark. Contains a considerable number of fragments of lignite.
30	1	0	81	8	Lignite.—Rather brittle. Not very woody. Contains ferns.
31		8	82	4	Clay.—Very dark. Some broken lignite.
32		11	83	3	Lignite. Very woody, tough, and extremely hard.
33	2	2	85	5	Clay.—Dark lead-colour. Contains broken lignite.
34		10	86	3	Lignite.—Very woody and rather tough. Contains seeds.
35	2	2	88	5	Clay.—Dark lead-colour. Contains pieces of lignite lying at all angles to the plane of the bed.
36		1	88	6	Lignite.
37	1	11	90	5	Clay.—Very dark lead-colour. Very brittle. Rich in pieces of lignite; the thickness of the bed somewhat variable.
38		4	90	9	Lignite.—Woody, and rather tough.
39		10	91	7	Clay.—Readily falls into fragments, which generally have plane, but sometimes curved surfaces. Contains pieces of lignite.
40	1	0	92	7	Lignite.—This bed is very uniform in thickness, and well-defined at each surface. Very compact and rather tough. Contains a few seeds. One specimen of *Sequoia Couttsiæ* was found here.
41	1	6	94	1	Clay.—Dark. So brittle as to fall in pieces at the least touch. Contains pieces of lignite.
42		9	94	10	Lignite.—Extremely brittle. The bed is somewhat irregular in thickness and obscure in definition.
43		9	95	7	Clay.—Lead-colour.
44		6	96	1	Lignite.—Irregular in thickness. Occasionally intersected by veins of clay, commonly at right angles to the plane of the bed.
45		7	96	8	Clay.—Dark. Fragments of lignite very abundant.
46		9	97	5	Lignite.—Very compact and tough. Abounds in seeds.
47	1	4	98	9	Clay.—Dull lead-colour in the upper part, changing into a darker hue towards the base; the upper band is tougher than the lower; the latter contains many pieces of lignite.
48		7	99	4	Lignite.—Compact. Contains seeds, and a few young circinate fern-fronds.

* Quart. Journ. Geol. Soc. vol. xii. p. 354.

Beds.	Thickness. ft.	in.	Totals. ft.	in.	
49		10	100	2	Clay.—Rather light lead-colour. Somewhat tough. Contains pieces of lignite smaller than usual.
50	1	0	101	2	Lignite.—Compact. Very tough. Yields large slabs of "Board Coal"*.
51		9	101	11	Clay.—Very dark. Contains a few pieces of lignite.
52		3	102	2	Lignite.—Loose and soft.
53		7	102	9	Clay.—Brown. Pieces of lignite abundant in the upper part, less so towards the base.
54	2	3	105	0	Lignite.—Compact, tough, woody. Yields large slabs of "Board Coal" having a mottled appearance. Contains a few seeds.
55		10	105	10	Clay.—Very dark blue. Of resinous aspect. Contained a piece of lignite six feet long and two inches broad; smaller fragments rather numerous.
56	3	2	109	0	Lignite.—Very woody. Frequently has a "charred" appearance.
57		5	109	5	Clay.—Blue. Brittle.
58	1	8	111	1	Lignite.—Woody, "charred" and mottled. Contains a few seeds; none occur where the lignite appears "charred."
59		4	111	5	Clay.—Some parts blue, others dark drab.
60	1	8	113	1	Lignite.—Woody, hard, brittle. Has a fracture resembling that of ordinary coal. Contains seeds.
61		4	113	5	Clay.—Blue and dark drab.
62	2	4	115	9	Lignite.—This bed consists of two bands: the upper, nine inches thick, breaks into irregularly shaped "glassy" pieces; the lower is very hard, light-brown, less heavy than the lignite usually is, brittle, woody, and has a fracture resembling that of ordinary coal. This band contains seeds, none of which appear in the upper. The bands graduate into one another through a thin layer of "charred" lignite.
63		6	116	3	Clay.—Light lead-colour. Contains seeds, probably more than one species. One stem of *Sequoia Couttsiæ* was found here.
64	1	3	117	6	Lignite.—Very hard and compact; not quite so tough as some of the beds above it, but by no means brittle; possesses traces of the "charred" character.
65		3	117	9	Clay.—Lead-colour. Resinous in aspect. Contains numerous pieces of lignite.
66	1	4	119	1	Lignite.—In all respects like the 64th bed.
67		2	119	3	Clay.—Resinous appearance.
68	1	4	120	7	Lignite.—In all respects like the 64th and 66th beds.
69		2	120	9	Clay.—Very brittle, laminated, and resinous in aspect.
70		3	121	0	Lignite.
71		1	121	1	Clay.
72	4	0	125	1	Lignite.—Termed by the workmen the "Last Bed"†.

In order to ascertain whether the succession and characters of the beds are the same in other parts of the pit, two other sections were made, also in the southern wall, one about 460, and the other 680 feet eastward from the first. The results are given below.

* So named from having an appearance resembling "deal boards."

† This section is exhibited in Plate LIII.

Section 2, of the Bovey Deposit, in the south wall of the "Coal-pit," 460 feet eastward from Section 1. Dip 12½° towards S. 35° W. (magn.).

Beds.	Thickness. ft.	in.	Totals. ft.	in.	
1	6	2	6	2	Sandy Clay.—With angular and subangular stones; the upper six inches peaty soil, in which the stones also occur.
2	4	10	11	0	Clay.—Contains some fragments of lignite.
3	7	10	18	10	Sand.—Quartzose and ferruginous.
4	10	5	29	3	Clay.—In some parts sandy and of a buff colour, in others dark with vegetable débris. Much fragmentary lignite.
5		9	30	0	Lignite.—Woody and brittle.
6	1	7	31	7	Clay.—Dull lead-colour.
7	1	5	33	0	Lignite.—A matted mass of débris of *Sequoia Couttsiæ* and ferns.
8	2	0	35	0	Clay.—Light drab. Roughly laminated. Contains broken lignite.
9					
10					Do not occur in this section.
11					
12	1	3	36	3	Clay.—In some parts black with vegetable matter, in others light drab; the former most prevalent.
13		4	36	7	Lignite.—Much broken.
14	2	1	38	8	Clay.—Light drab. Much broken lignite near the top.
15		6	39	2	Lignite.—More compact than in the higher beds.
16	2	2	41	4	Clay.—Dull lead-colour. Somewhat resinous aspect. Broken into fragments having more or less curved surfaces.
17	1	0	42	4	Lignite.—Contains dicotyledonous leaves.
18	1	9	44	1	Clay.—Dark drab colour. Much broken into angular fragments. Contains pieces of lignite.
19	1	2	45	3	Lignite.—Contains a considerable quantity of clay, in almost continuous bands.
20	1	2	46	5	Clay.—Rich in fragments of lignite.
21	2	5	48	10	Lignite.—Compact.
22	1	3	50	1	Clay.—Dull drab colour.
23		10	50	11	Lignite.—Much broken; the fragments having well-defined clay-stained surfaces.
24		9	51	8	Clay.—Light drab. Broken. Resinous in aspect.
25	5	10	57	6	Lignite.—Contains patches of clay. Ferns and the so-called "flabelliform leaves" occur near the base.
26	3	6	61	0	Clay.—Light drab. Rich in stems, leaves, and fruits of *Sequoia Couttsiæ*.
27	1	7	62	7	Sand.—Quartzose and ferruginous. Contains lenticular patches of clay.
28		6	63	1	Clay.—Light colour.
29	3	9	66	10	Clay.—Dark colour.

The nature of the ground prevented the second and third sections being satisfactorily continued below the 29th bed. There is reason to believe, however, that the still lower beds are uniform in character and order throughout the pit.

In the third section the materials comprising the various beds will be named without remark, since those which agree numerically agree very closely geologically.

Section 3, *of the Bovey Deposit, in the south wall of the "Coal-pit," 680 feet eastward from Section* 1, *and 220 feet from Section* 2. *Dip* 12½° *towards S.* 35° *W.* (*magn.*).

Beds.	Thickness. ft.	in.	Totals. ft.	in.	
1	10	9	10	9	Sandy Clay.—With angular and subangular stones.
2	1	0	11	9	Clay.
3	12	6	24	3	Sand.
4	2	0	26	3	Clay.
5		6	26	9	Lignite.
6	1	0	27	9	Clay.
7	1	9	29	6	Lignite.
8					
9					Do not occur in this section.
10					
11					
12	1	8	31	2	Clay.
13		10	32	0	Lignite.
14	2	4	34	4	Clay.
15	1	4	35	8	Lignite.
16	3	0	38	8	Clay.
17	2	0	40	8	Lignite.
18	2	0	42	8	Clay.
19	2	0	44	8	Lignite.
20		6	45	2	Clay.
21	3	1	48	3	Lignite.
22	1	0	49	3	Clay.
23		11	50	2	Lignite.
24		6	50	8	Clay.
25	5	3	55	11	Lignite.
26	3	2	59	1	Clay.
27		10	59	11	Sand.
28		7	60	6	Clay.
29	3	2	63	8	Clay.

On comparison, it will be found that the 9th, 10th, and 11th beds of Section 1—the first and last being sand and the second clay—do not occur in either of the other two sections, and that in Section 3 another clay-bed is also missing. This last is supposed to be the 8th, but it would probably be difficult to determine between it and the 12th. It is possible, moreover, that the bed numbered 12 in the third may represent both the 8th *and* 12th of the two other sections. The same numbering has been retained in all the sections to facilitate comparison.

The total thickness of the missing beds amounts to no more than about 5 feet; the fact, however, that they are not present may be significant. It amounts to this: by removing 460 feet further into the ancient Bovey lake (for such I assume the area to have been)—460 feet further from its ancient shore, that shore being the granitic region of Dartmoor,—we leave behind two thin beds of sand, which do not reappear when we advance 220 feet further in the same direction.

Eliminating these beds, we have no sand in the series below the uppermost bed of lignite (No. 5) excepting No. 27, which occurs in all the sections, and, indeed, constitutes a marked feature in the deposit as exposed at the "Coal-pit." It is 133 inches thick in the first section, no more than 19 in the second, and dwindles to 10 inches only in the third; but no bed is more continuous or better marked: its comparatively bright colour catches the eye, and indicates its presence along the entire length of the excavation. It attains a still greater thickness in the western wall of the pit. Between the first and third sections it forms an inclined plane 680 feet long and 123 inches high; or base : height = 8160 : 123 = rad : tan 52′; so that, great as the attenuation is, it merely produces a gradient of 1 in about 66, or an inclination of less than one degree.

The sections show that a similar eastward diminution of thickness characterizes the 28th bed.

This attenuation, like the thinning out of the beds previously mentioned, (which, it may not be out of place to remark, is in the direction of the *Strike* of the deposit,) is probably an indication, were one needed, that the detrital layers were formed at the expense of the Dartmoor granite.

The sections agree in naturally dividing themselves into three parts or series, viz.—

1st. The bed No. 1, of Sandy Clay, containing angular and subangular stones.

No stones of any kind were met with below this.

2nd. The beds from the 2nd to the 27th, both inclusive, composed of sand, clay, and lignite.

3rd. All the beds below the 27th, consisting of clay and lignite only*.

It appears that that portion of the age of the deposit, which is represented by the first (that is, lowest) forty-five beds was unmarked by the deposition of sand within that area. Forty-four beds of lignite and clay, having an aggregate thickness of upwards of 47 feet, succeed each other alternately in regular unbroken order; the next bed, however (28th in the sections), instead of being a mass of vegetable matter, as was due, is a second bed of clay, and, in the first section, of unequalled thickness; this is followed by a thick bed of sand, the first which presented itself. Clearly some change must have occurred. Had the accumulated deposit so far shallowed the waters of the ancient lake? Had it conveyed its western margin so far eastward, that sand was to be henceforward deposited in the area hitherto appropriated to clay, instead of further west as heretofore? If so, it might have been expected that the change would have been less sudden. No sand whatever had previously occurred. Moreover, on this hypothesis it is reasonable to suppose that sand would have been largely deposited in future, instead of which the old order (of clay and lignite alternately) is continued for eighteen additional beds, increasing the depth of the deposit by nearly 40 feet; indeed, omitting the two arenaceous beds (9th and 11th) which occur only in the first section, we have no more sand until the uppermost bed of lignite in the sections had been formed. In no instance does the lignite rest on or support sand, but always clay.

* See Plate LIII.

Almost all the clay-beds contain fragments of lignite, which are commonly, at least approximately, parallel to the plane of stratification. One or two exceptions to this were met with, the most marked being that of the 35th bed, where they occur at all angles to that plane.

Though when first dug the clay is not generally characterized by lamination, exposure to the atmosphere, in most cases, developes this quality.

Fossils were found in only fifteen of the beds, namely, one of clay and four of lignite in the second series, and one of the former and nine of the latter in the third or lowest. It is only necessary to particularize the 7th, 25th, 26th, and 46th beds.

The 7th is chiefly remarkable as being a mat composed of fragments of the coniferous tree *Sequoia Couttsiæ*, Heer, and of the fern *Pecopteris lignitum*, Gieb.

The 25th is that in which the so-called "flabelliform leaves" chiefly occur; a few were also met with in the 17th bed. Professor Heer has identified them as the rhizomes of ferns. Some of them were fully 5 feet in length, but too brittle to be got out entire. In most cases the large specimens have a curved outline. The lowest three inches of the bed is commonly a mat of fragmentary fronds of the ferns *Pecopteris lignitum* and *Lastrea stiriaca*, Ung.,—the first being the most prevalent. Above this lie the rhizomes, in a continuous band about 6 inches thick. Though these bands generally preserve a well-marked separation, they sometimes inosculate, but never so as to show whether the fossils were parts of the same plant. The uppermost portion of the bed consists of slabs of "board coal" of great length, and of a width indicating the existence of trees (probably *Sequoia Couttsiæ*) fully 6 feet in diameter. Bodies occur in this bed having the appearance of roots, with rootlets passing into the clay below. Mr. Keeping reported one such "root" having a part of the stem of a tree still attached to it, the latter being almost perpendicular to the plane of stratification. The lignite in this stratum not unfrequently presents a fretted aspect, as if from some kind of corrosive action; in these cases it is crossed by cracks or fissures of variable width, having rugged walls, and filled with yellow ochre.

The 26th is the most important bed in the series, being rich in both the number and the variety of its fossils. The lowest six inches contain a large number of dicotyledonous leaves, most of them crushed and valueless; occasionally, however, nests or patches of such leaves occur in a better condition. A few twigs of *Sequoia Couttsiæ* are also found in this lowest band; whilst quite at its base are numerous branches of the same plant, measuring in some instances 3 feet in length and from a quarter of an inch to 4 inches wide. In most cases the large specimens are extremely brittle.

The next fifteen inches constitute a middle band, containing some *Sequoia*-débris and a considerable number of crushed leaves, the latter suggesting the idea that they had been deposited on a very uneven surface. A thin layer of "charred" lignite, several feet in length, was found in the middle of this band.

The remaining part of the bed (the uppermost four inches) abounds in seeds of various kinds; but it is chiefly marked by remains of *Sequoia*. It is not too much to say that

every museum in the world might readily be supplied with thousands of specimens of this plant from this band. It is represented by branches, twigs covered with leaves, fruits (sometimes, but more frequently not, attached to the twigs), and seeds. A few dicotyledonous leaves occur here also.

Though most abundant in this bed, the *Sequoia* occurs also in the 7th, 40th, and 63rd —that is, the highest and lowest beds which have yielded fossils. The Bovey deposit evidently represents but one flora.

The 46th bed yielded a very large number of small seed-vessels (*Carpolithes nitens*, Heer), which, like those described by Dr. Hooker, in 1855, under the name of *Folliculites minutulus*, but which Professor Heer has identified as *Carpolithes Websteri*, Br., are "thickly strewed over the surfaces of the laminæ of lignite, and slightly imbedded in them as if the latter had been soft when the deposit was formed. They lie in all directions, but always on their flat surfaces"*. They are by no means confined to this bed, though more abundant in it than elsewhere.

Nothing resembling the cone of *Pinus sylvestris*, described by Dr. Hooker, was found during our exploration. But for its complete "carbonization and bituminization," I should believe that it belonged to a neighbouring bog, mentioned by several writers, "from which have been taken, several feet below the surface, many trees of the fir kind; several 18 inches in diameter, together with pine-nuts, but no coal"†.

In some of the lower beds, close-fitting joints not unfrequently occur in the lignite, the surfaces of which (rarely planes) have a high polish: the workmen call such pieces "glassy;" and the term aptly expresses the character. They also call them "slides," believing them to be "Slickensides." There do not appear to be any "faults" in the beds at the pit.

It has already been stated that the lignite often has a "charred" appearance; and indeed it is somewhat difficult to believe that it has not ignited spontaneously; nor are we without facts which give some support to this opinion. It is well ascertained that the combustion so prevalent in the heaps of refuse is spontaneous, and the lignite beds are sometimes found to be on fire in the tunnels or "ends." Mr. Divett, writing me on this question, says, "Some ten or twelve years since, I found a fire raging in an 'end' at the western extremity of the pit, which had been abandoned for some months. I enclosed the main western 'end' with a dam of timber and clay, in the hope of extinguishing the fire, but only succeeded in checking it. This part of the pit was buried by a run of clay from the north for many years, and was excavated again about twelve months since, when the fire was still burning. It is now again buried by 'run' sand. I have never doubted that this ignition was spontaneous." Mr. Hatchett, however, who gave much attention to the chemistry of the lignite, was of opinion that there was no evidence of true combustion‡.

* Quart. Journ. Geol. Soc. vol. xi. p. 566.

† Mr. Scammell, in Parkinson's 'Organic Remains,' vol. i. Letter 12, p. 129.

‡ Trans. Linn. Soc. vol. iv. p. 141, &c.; also Philosophical Transactions for 1804, Part I. p. 396, &c.

Newly exposed surfaces of the laminæ of the lignite are sometimes more or less covered with stellate crystals of selenite. Their beauty is very striking, and is enhanced by contrast with the dull dark surface on which they lie; unfortunately it is by no means durable; the stars first lose their brilliancy, after which many of them disappear altogether.

Fragmentary pieces of lignite occasionally occur in the "coal-beds" as well as in the clay; some of them are perfectly flat slabs, of various sizes, having sides and ends as true and angular as if they had been something more than rough-hewn in a carpenter's shop. Others have an appearance resembling stranded drift-wood; I found a well-marked piece of this character in the 72nd bed.

The flattened form which the "board coal" commonly assumes is by no means confined to the lowest beds; it is as characteristic of the 5th, or uppermost, and of that portion of it which most nearly reaches the surface, as of any bed in the pit sections. As pressure must be regarded as essential to this flatness, though probably not its sole cause*, it seems impossible to avoid the conclusion that much of the superior portion of the deposit has been removed by denudation. It must not be supposed, however, that all samples of "board coal," taken from any one bed, are equally flattened. Examples occasionally present themselves, of portions of stems and branches, in which the original curvature of outline is not entirely obliterated—the transverse section distinctly showing the rings of annual growth converted into ellipses of great excentricity. Good instances of this have been met with in the lowest beds.

The stones so abundant in the "Head," or uppermost division of the pit sections, are sufficient to show that it was formed under conditions dissimilar to those which produced the two lower series. Moreover, it lies unconformably on them. Nowhere in the excavation do the lignite and interstratified beds reach the surface; they are cut off at distances varying from 3 to 7 feet below it, as is shown in Plate LIII.

It has already been stated that the stones of the "Head" are generally angular or subangular; occasionally, however, some occur that are much rounded. They vary in size, from blocks upwards of a foot in mean diameter to pieces not larger than hazel-nuts. On Bovey Heathfield they are fragments of granite, metamorphic rock, carbonaceous grit, and trap, with a very few of flint and chert. The two last increase in number eastward—that is, with increased proximity to the Cretaceous district,—and in some localities are even more abundant than other detritus.

In no instance have I found or heard of limestone-fragments on the Bovey Heathfield. A transporting current from the north or north-north-east seems to be required to meet the facts of the case. Were it not for the samples of flint and chert, a movement from the west or north-west, or even south-west, might have supplied the materials. No agent progressing from any part of the compass between the north-east and south-west, through south, could have furnished the granite-blocks or failed to transport large quantities of limestone-débris. On the whole I incline to a transportation from a

* See Hatchett in Philosophical Transactions for 1804, Part I. p 897.

northerly direction, rather east than west of true north,—that is, a current, or other agent, moving in a line nearly at right angles to that in which the sands and clays of the true Bovey beds travelled from Dartmoor—a fact, concurring with those previously mentioned, in favour of a great chronological interval between the "Head" and the deposit it covers.

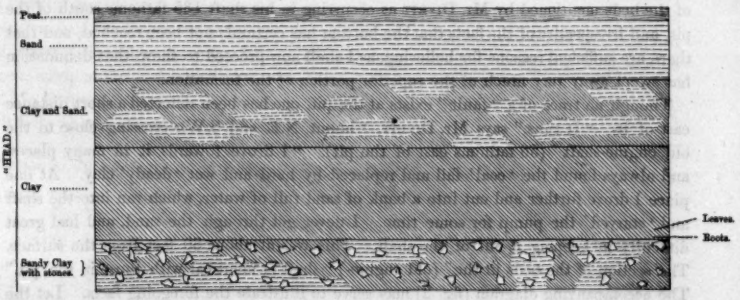
Nor are we without *organic* evidence of the lapse of time between these formations. During our exploration at Bovey, I had an opportunity of examining and measuring a section made by workmen digging clay, in the "Head," on the Heathfield, about a quarter of a mile east of the pit. The results were as below.

Section 4, of the "Head" at Bovey Heathfield.

Beds.	Thickness. ft.	in.	Totals. ft.	in.	
1*		6		6	Peat.
2	2	6	3	0	Sand.—Fine, white, quartzose.
3	3	0	6	0	Clay and Sand.—In separate masses, but not distinctly stratified. The clay more abundant than the sand.
4	4	0	10	0	Clay.—Very white.
5	unknown.				Sandy Clay.—With angular and subangular stones.

Some time afterward we found a considerable number of dicotyledonous leaves, lying in the white clay, nine feet below the surface of the plain, and immediately below them lay some large roots. Professor Heer assigns the leaves to a period much more modern than that represented by the lignite-beds, yet to one characterized by a "colder climate than Devonshire has at the present day," thus confirming Mr. Godwin-Austen's opinion, that the "Head" belongs to the "period prior to the most recent change of climate"†. The position of the leaves is indicated in fig. 1, which is drawn on the scale of 0·2 inch to 1 foot.

Fig. 1.



* The beds in this section and in those which succeed, do not represent those which bear the same numerals in the pit sections.

† Geol. Trans. 2nd Series, vol. vi. p. 437, &c.

Though in the pit section No. 1 the 5th is the highest, and the 72nd the lowest bed of lignite, it would manifestly be unsafe to conclude that no higher or lower beds exist; and indeed Mr. DIVETT, in a letter on this point, says, "In a shaft sunk 135 fathoms south of the pit" (*i. e.* in the direction of the *dip* of the beds) "I had, in 99 feet sinking, some good beds of coal. When we ceased to sink we had, I believe, some six or seven fathoms between us and the top of the uppermost bed of lignite in your sections." This estimate, as to the depth at which the "5th" bed would have been cut, is fully borne out by the *dip* of the beds and the distance of the shaft, if we assume that no "fault" exists in the interval and the *dip* remains constant. On both these points we have direct confirmatory evidence for the distance of sixty-three fathoms south of the pit, as subterranean workings have been carried so far, "by driving down the dip," and show that the beds exist in unbroken continuity and uniform inclination; that is, the beds have been followed to a depth of 80 feet below the bottom of the "Coal-pit."

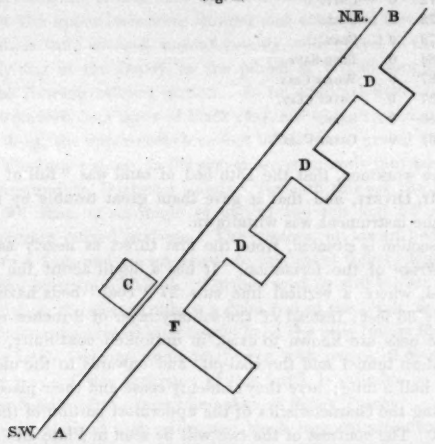
Though the workmen have named the 72nd the "last bed," it is no more than an expression of the fact that it is the last or lowest they work. That there are still lower beds is certain, since Mr. DIVETT says, "I sank a shaft about 13 feet" (below the bottom of the pit) "and cut two tolerable beds of coal." The workmen speak of still earlier and deeper borings, and state that thin layers, or "shells," of lignite were found separated by thick beds of "muddy clay." Omitting these traditions, however, we are now in possession of the following figures. The 72nd, or "last" bed is, at the western end of the pit, about 100 feet vertically below the surface of the plain; or, measured at right angles to the plane of stratification, we have, to the base of this bed, a thickness for the deposit of 125 feet*; the pit beds have been followed 80 feet lower, and lignite has been cut 13 feet below the so-called "last" bed; giving an aggregate of 218 feet, inclusive of the "Head," or upwards of 35 fathoms for the true Bovey deposit; exclusive of the beds mentioned by Mr. DIVETT as occurring in his shaft 135 fathoms south of the pit, and irrespective of the facts that the bottom has certainly not been reached, and that there are sufficient reasons for believing, as I shall now proceed to show, that denudation has swept away very much of the superior portion of the formation.

Though no trace of a "fault" exists at the pit, one has been detected a short distance east of it. "It runs," says Mr. DIVETT, "about N.E. and S.W., crossing close to the old engine-shaft" (56 fathoms east of the pit). "I drove towards it in many places, and always found the 'coal' fail and replaced by hard and wet 'deady' clay. At one place I drove further and cut into a bank of sand full of water, which ran into the shaft and 'starved' the pump for some time. I never got through the sand, and had great difficulty in keeping it out of the shaft. This was at about 80 feet from the surface. The section of the beds in the" (old engine-) "shaft is identical with those in the pit." The accompanying diagram (fig. 2) may serve to illustrate the foregoing facts. Let the surface of the paper represent a horizontal plane, on the level of the bottom of the coal-

* See Section 1, page 1024.

pit, at its eastern end, about 80 feet below the surface. Let A B be a portion of a tunnel, or "working," on that level, on the eastern side of the pit, running, about N.E.

Fig. 2.



and S.W., near and parallel to the plane of the "fault." C the old engine-shaft, 56 fathoms east of the pit. D and F various places at which Mr. DIVETT drove horizontally from the eastern side of the tunnel. In doing so he "always found the coal fail and replaced by hard and wet 'deady' clay;" at F he "drove further, and cut into a bank of sand;" in fact he seems here to have cut *through*, but elsewhere *into*, a dyke composed of heterogeneous materials; beyond which he encountered a bed of "sand full of water;" doubtless the 13th bed in the following section (No. 5), which, it will be seen, exists at the required depth ("80 feet below the surface"*).

Mr. DIVETT proceeds to say, "About 70 fathoms east of the shaft, I bored, in 1855, 99 feet, when I obtained the following section."

Section 5. 70 *fathoms east of the Fault on Bovey Heathfield* (furnished by J. DIVETT, Esq.).

Beds.	Thickness. ft.	in.	Totals. ft.	in.	
1	13	0	13	0	GRAVELS AND CLAYS.—("Head.")
2	11	0	24	0	SAND.
3	4	0	28	0	BLACK CLAY.
4	2	0	30	0	"DEADY GROUND."
5	6	0	36	0	SAND.
6	3	6	39	6	CLAY.
7	4	6	44	0	SAND.

* See Plate LIV.

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Beds.	Thickness. ft.	in.	Totals. ft.	in.	
8	8	0	52	0	Clay.
9	13	0	65	0	Sand.
10	7	0	72	0	Clay.
11		2	72	2	Coal.
12		10	73	0	Clay.
13	11	0	84	0	Blue Sand.
14	3	0	87	0	White Clay.
15		6	87	6	Coaly Clay.
16	1	6	89	0	Sand.
17	10	0	99	0	Coaly Clay*.

I learn from the workmen, that the 13th bed of sand was "full of water," like that encountered by Mr. Divett, and that it gave them great trouble by running into the boring whenever the instrument was withdrawn.

The foregoing section is situated, from the first three, as nearly as possible in the direction of the *Strike* of the formation. It has a depth about the same as the pit at its western end, where a vertical line cuts 27 "coal" beds having an aggregate thickness of nearly 36 feet; instead of the solitary layer of 2 inches only in the Table just given. Those beds are known to exist, in unbroken continuity, along the entire length of the western tunnel and the coal-pit, and onwards to the old engine-shaft, a distance of nearly half a mile; here they suddenly cease and their place is supplied by a series of beds having the characteristics of the uppermost portion of the second division of the pit sections. The contrast of the two will be seen in Plate LIV.

There can be no doubt that these facts are evidence of a great fault; that the beds on the east of it are an upper portion of the Bovey deposit, preserved, through the intervention of a vertical displacement of at least 100 feet, from the denuding action which swept it away on the west, after it had, by its pressure, assisted to flatten the timber in the uppermost stratum of lignite at present existing there; and that this denudation occurred before the deposition of the "Head," since this is found covering the deposit alike, without considerable variation in its thickness, on each side of the "*fault*." It will be understood that it is by no means intended to intimate that this is the only fault in the Bovey formation; the occurrence of beds of lignite, near the surface, in various parts of the Heathfield, renders it probable that there is, at least, another. Nor is it meant to express the opinion that the "Head" itself may not have lost much by denudation; so far as they are at present understood, certain facts seem to imply that it may have suffered much in this way.

Though the neighbourhood of Bovey was necessarily regarded as the head-quarters of the formation, it was felt to be desirable that some attention should be given to certain other localities, in various parts of the basin, where clay-pits exist.

The clay-works at Aller, in the parish of Abbotskerswill, adjacent to the road from Torquay to Newton, and about two miles from the latter, have been abandoned some years. Lignite seems to have been found there in considerable quantity. Samples of

* This section is exhibited in Plate LIV. (eastern section).

it, shown me by one of the old workmen, displayed the common woody character so usual at Bovey, but no traces of leaves or other fossils. There appear to have been seven distinct beds of lignite alternating with as many of clay, the latter from 2 to 4 feet thick. Of the former, the lowest were the most compact, and were from 3 to 3½ feet in thickness, whilst the upper ones were thinner and contained a considerable admixture of clay. The whole were covered, unconformably, with gravel to the depth of 20 feet.

Clay is largely dug at the Decoy, in the parish of Woolborough, about half a mile south-west of the Newton railway station. In an artificial dyke, or water-course, two beds of lignite, separated by a layer of black clay, are well exposed. The entire cutting is about 10 feet deep, the uppermost three feet being coarse gravel surmounted by a thin layer of peat. The larger stones in the gravel are commonly flint and chert, the smaller are partly, perhaps mainly, Dartmoor débris. Beneath this are the Bovey beds dipping towards north 80° East, at an angle of 60° at the top and 50° at the bottom, the beds having somewhat curved surfaces. The western, or lowest bed of lignite is 9 feet thick, the eastern 6 feet, and the intermediate clay about 5 feet; the whole lies between clay similar to the interstratified bed. Further west, or still lower, is a valuable bed of "pipeclay," whilst on the eastern side is a good bed of the black, or "potter's clay."

Though we spent some days seeking fossils here, the only things found were two small bodies, probably seeds, and one undoubted twig, with leaves, of *Sequoia Couttsiæ*. The latter, though a very inferior specimen of this fossil, is valuable as a link of identification between the lignite of the Decoy and that of Bovey Tracey.

Considerable quantities of both white and black clay are also excavated in the parish of Kingsteignton, about two miles north of Newton, very near the eastern margin of the deposit. I measured the following section in one of Mr. Whiteway's "black pits."

Section 6, *of the Bovey Deposit near Kingsteignton.*

Beds.	Thickness. ft.	in.	Totals. ft.	in.	
1	15	0	15	0	"Head," consisting of angular and subangular flint, chert, and Dartmoor débris.
2	2	8	17	8	Clay.—Black. "Not Saving."
3	1	6	19	2	Clay with Lignite.
4	4	0	23	2	Clay and Sand.—Contains root-like portions of lignite.
5	4	0	27	2	"Shovel" Sand.—Thickness variable.
6	8	0	35	2	Clay.—Black. "Saving."
7	3	0	38	2	Clay.—Black. "Short." Thickness variable.
8	12	0	50	2	"Bottom" Clay.—"Saving."
9	Thickness unknown.				Sand.

The workmen denominate the clay "Saving" or "Not Saving," according as it has or has not a commercial value. Sand so loose as to be capable of removal by the use of a spade or shovel only, is termed "Shovel" Sand. Clay but slightly plastic is spoken of as "Short;" and "Bottom" Clay expresses the fact that no argillaceous deposit, having commercial value, is found below it.

None of the workmen appear to have found or heard of anything in the shape of

gravel at the base of the clay series*. Sometimes, but not frequently, small, well-rounded, smooth quartz pebbles, about the size of a common pea, occur in the best clay; and mundic is said to be not uncommon.

The *dip* of the beds at this pit is about 8° towards N. 50° W. It is said to vary somewhat both in amount and direction, but is generally less northerly than the above. As at the Decoy, the white clay underlies the black.

Though lignite occurs here, it is less abundant than in either of the other areas which have been mentioned; from the report of the workmen, however, it is occasionally found, especially in the pits more removed from the margin of the deposit, in larger bodies than in the section just given. Our search for fossils was altogether without success.

At the suggestion of Dr. Falconer, and also of Sir Charles Lyell, it was decided to submit the collection of fossils, which we had made at Bovey, to Professor Heer of Zürich, in the hope that he would succeed in extracting from them their chronological secret. Accordingly, the necessary arrangements having been made by Sir Charles Lyell, I sent him all the drawings of the fossils, prepared by Mr. Fitch of Kew, together with a large and, so far as I could judge, characteristic series of the specimens themselves, and in a short time had the gratification of learning that he had determined forty-five species of plants, of which forty-one were from the lignite series and four from the "Head," the former being decidedly of the lower miocene age, whilst the latter were much more modern.

Though, when he subsequently reached this country, Professor Heer failed to detect, in the remainder (the bulk) of the collection, any species which he had not previously seen, he was more fortunate at Bovey; where, in the few days he was able to devote to the deposit, he added nine new species of fossil plants to the list, and, by the discovery of an insect, *Buprestes Falconeri*, detected the first evidence of animal life which has been exhumed there.

From the decision just mentioned, it appears that the Bovey lignites are the contemporaries of the "Hempstead Beds" in the Isle of Wight, first discovered by the late lamented Professor Edward Forbes in 1852, and described by him in the following year†. Though their discoverer always regarded them as Upper Eocene, they have recently been grouped amongst the Lower Miocene‡; this, however, is a question of classification; wherever they find a resting-place, the Bovey beds must accompany them, since they are on, or very near, the same horizon.

The ancient miocene lake of Devonshire which we have been considering, must have been of great depth; the lowest figures mentioned in an earlier page give at least 35 fathoms, whilst, if to this we add those obtained from the "fault," it amounts to fully 50 fathoms; indeed the clay-workers assert that their borings sometimes amount to quite this depth. The present surface of the plain, however, is, at the pit, no more

* See Mr. Godwin-Austen, in Trans. Geol. Soc. 2nd Series, vol. vi. part 2, p. 448; also Sir H. De la Beche, in his 'Report,' p. 257.

† Quart. Journ. Geol. Soc. vol. ix. p. 259, &c.

‡ Sir C. Lyell's 'Supplement' to the fifth edition of his 'Manual,' p. 6, &c., 1857.

than 15 fathoms above the ordinary level of spring-tide high water, so that the bottom of the lake would be at least 35 fathoms below the level of the sea. Yet, says Professor Heer, and apparently on unimpeachable data, "it was a fresh-water lake." The country, then, must have stood at a much higher level than at present, or a barrier existed between the lake and the sea. Unless, however, there have been very local changes of level, the former hypothesis is disposed of by the fact that the Hempstead beds are of fluvio-marine origin, and must therefore have been formed at a level much below that which they at present occupy. A barrier, then, must have existed somewhere in the present tidal estuary of the Teign, over which the surplus waters of the lake passed to the ocean, or which, by its superior height, caused the waters to find an outlet in Torbay. Judging from the physical features of the two valleys leading from Newton to the English Channel, one by Teignmouth and the other by Torquay, the former is far more likely than the latter to have been the course followed.

The period represented by the Bovey beds must have been of considerable duration. So far as the strata themselves show, it was, in the district under consideration, one of great tranquillity. A long series of beds, alternately vegetable matter and fine clay, succeed each other in scarcely interrupted order; the three intruded arenaceous layers probably mark nothing more than a somewhat increased velocity in the current, or river, which conveyed the detritus of the granite hills of Dartmoor into the area of deposition, but which, instead of being permanent, was as short-lived as it was unusual.

The late investigations at Bovey, then, have been so far successful that they have settled the vexed question of the age of the deposits occurring there,—added forty-nine species to the fossil flora of this country, of which twenty-six are new to science,—recognized the first traces of animal life which the deposit has yielded,—detected another British fragment of the miocene page of the earth's history, which, until 1857, was supposed to be totally unrepresented in England,—taken us back to a remote period when the slopes of Devonshire were clothed with a luxuriant subtropical vegetation,—and separated, by a wide chronological hiatus, the lignite and associated beds from the gravels overlying them—a hiatus evidenced by the dissimilarity and unconformability of the two series, by a change in the direction by which detrital matter reached the Bovey area, by great vertical displacements of the lower series, followed by denudation of the consequent surface-inequalities prior to the deposition of the upper, and by the exchange of an extinct flora, requiring a high temperature, for an existing one, which is now confined to arctic and alpine regions.

Remote, however, as was the earliest of the two periods thus represented, the great leading geographical features of the district were pretty much as at present. The Teign and Bovey rivers were then in existence, but instead of the latter being tributary to the former, their mouths were three miles apart, and both fell into the same deep, sluggish, fresh-water lake; occupying the site of the present Bovey plain, and guarded by Dartmoor and the other hills which still constitute the prominent characteristics of the district.

Explanation of the Plates.

PLATE LII.

Is copied, with very slight alterations, from the twenty-sixth sheet of the Map published by the Geological Survey of Great Britain; and, like the original, is on the scale of 1 inch to a mile.

PLATE LIII.

Is a section of the Bovey formation, in the plane of the *Dip* of the beds. It is drawn, from the measurements obtained in the "first section," given in the text (see p. 1022, &c.), on the scale of $\frac{1}{1584}$, or 1 inch to 14 feet. The *Dip* amounts to $12\frac{1}{2}°$, and is in the direction S. 35° W. magnetic. The beds in which fossils were found are those the numbers of which are placed opposite them in the margins.

PLATE LIV.

Contains two sections of the formation, in the plane of the *Strike* of the beds, and is intended to show the nature of the evidence for the existence of the "*Fault*." The scale of thickness, in each, is $\frac{1}{120}$, or 1 inch to 10 feet; and the total depth below the surface is 99 feet.

The symbols have the same meaning in both.

a is the "old engine-shaft."

b. The eastern end of the "Coal-pit;" 56 fathoms west of *a*.

c. Mr. Divett's "boring;" 70 fathoms east of *a*.

d, 80 feet below the surface, is a horizontal excavation very near the engine-shaft, and opening eastward out of a "working" which runs parallel and adjacent to the "Fault" (see fig. 2).

e f is the hypothetical *plane* of the "Fault."

With the omission of a few unimportant local differences, the western section represents the ascertained succession and thickness of the beds from *a* to nearly half a mile westward. They are probably continued much further in this direction, but are known to terminate eastward abruptly at the "Fault," *e f*, immediately east of *a*. The lowest bed shown is the 62nd in the "pit" sections.

The eastern section is drawn from the data obtained in Mr. Divett's "boring" at *c*, (p. 1033,) and shows all the beds cut there. These are assumed to extend, in the same order, westward to *e f*; and though no excavations have been made at the surface in the intermediate space, the assumption is by no means gratuitous, since a bed of sand, having the same characters and at the same depth below the surface, has been met with both in the "boring" *c* and the excavation *d*.

Though the existence and situation of the "Fault" has been well ascertained, the angle which its plane (?), *e f*, makes with the horizon is not so well known. In the absence of complete evidence on this point, it has been thought best to draw it at right angles, more especially as the evidence, so far as it goes, is to that effect.

XI. *On the Fossil Flora of Bovey Tracey.* By Dr. Oswald Heer, *Professor of Botany, and Director of the Botanical Gardens in Zürich.* Communicated by Sir C. Lyell.

Received November 16,—Read November 21, 1861.

In the middle of the extensive plain which is bounded by the slopes of Bovey, are the potteries of Mr. Divett, for which fuel was formerly supplied by the lignite excavated there. In order to obtain this lignite a deep cutting has been made, and a sort of small ravine formed, on the sides of which the stratification is exposed. The surface-covering consists of a light-coloured quartzose sand, which contains here and there considerable beds of white clay. By the plants contained in it this formation is assigned to the Diluvium. Immediately under it come the beds of clay and lignite described by Mr. Pengelly in the foregoing paper, which are all referable to *one* formation, as several kinds of plants are common to the different beds. The *Sequoia Couttsiæ* and *Pecopteris lignitum* occur in the 7th, 17th, 26th, 40th, and 63rd beds. *Carpolithes Websteri* is certainly found in the greatest abundance in the 54th bed, yet occurs also, though very rarely, in the 25th bed; *Cinnamomum Scheuchzeri* and *C. lanceolatum* in the 17th and 26th. The formation to which these strata belong is far older than that of the overlying white clay; the plants found in the former prove them to belong unquestionably to the *Miocene* period, and accordingly we must treat of them separately.

A. *The Miocene Formation of Bovey.*

Of the fifty species of plants which have hitherto been discovered in the lignite beds of Bovey, twenty-one occur also on the Continent in the Miocene formation. The lignite of Bovey Tracey is therefore undoubtedly Miocene; and it is worthy of special remark, that the species of *Cinnamomum* which are so characteristic of the Miocene and so generally distributed through it make their appearance in Bovey precisely as in the lignites and molasse of the rest of Europe. Equally characteristic are the *Lastræa Stiriaca*, the fern of most universal distribution over Miocene Europe, the ornate striated seeds of the *Gardenia Wetzleri*, and the fruits of *Carpolithes Websteri*, which are known to us from Germany, Switzerland, and Italy.

The following conspectus exhibits the proportions in which some of the species found at Bovey have been observed in other districts:—

	Tongrian.	Aquitanian.	Mayencian.	Helvetian.	Œningian.
Lastræa Stiriaca, *Ung.*, sp.	.....	Monod; Hohe Rhonen; Paudèze; Wetterau; Ménat; Cadibona.	Radoboj; Eriz; Riethhäusli and Ruppen, St. Gallen.	.....	Albis, very rare; Parschlug; Sarzanello.
Pecopteris lignitum, *Gieb.*	Weissenfels	Thörens, Savoy; Manosque, Provence; Wetterau.	.....	.....	.....
Sequoia Couttsiæ, *m.* ...	Hempstead, Isle of Wight.	Armissan, near Narbonne.	.....	.....	.....
Palmacites Dæmonorops, *Ung.*, sp.	.....	Salzhausen	.....	.....	.....
Quercus Lyelli, *m.*	.....	Altsattel in Bohemia.	.....	.....	.....
Laurus primigenia, *Ung.*	Sotzka; Bornstedt; Weissenfels; Salzedo; Novale.	Rivaz; H. Rhonen; Spebach; Cadibona.	Eriz; St. Gallen	.....	.....
Cinnamomum Rossmässleri, *Hr.*	Hæring; Mt. Promina; Salzedo.	Rothenthurm; Altsattel; Reut; Westerwald; Sagor.	Lausanne; Solitude near St. Gallen; Radoboj; Bilin.	Turin	Albis; Wangen; Parschlug; Senegaglia.
—— Scheuchzeri, *Hr.* ...	Sotzka	Common everywhere.	Common everywhere.	Common ...	Common everywhere.
—— lanceolatum, *Ung.*, sp.	Common	Common everywhere.	Common everywhere.	Rare	Very rare; Albis; Ischel.
Daphnogene Ungeri, *Hr.*	Sotzka	Lignite of Bonn; Westerwald; Manosque.	Develier	.....	Irchel; Schrotzburg; Wangen.
Dryandroides hakeæfolia, *Ung.*	Sotzka; Mt. Promina; Hæring; Salzedo.	Monod; Rivaz; Rochette; H. Rhonen; Rufi; Baltenschweil; Sagor; Peissenberg; Foveagedo.	.....	.....	.....
—— lævigata, *Hr.*	Weissenfels	Monod; Rivaz; H. Rhonen; Peissenberg; Cadibona; Manosque.	.....	.....	.....
Nyssa europæa, *Ung.* ...	.....	Salzhausen; Nidda.	.....	.....	.....
Vaccinium acheronticum, *Ung.*	Sotzka; Sieblos; Hæring; Salzedo; Chiavon; Taurus.	Monod; H. Rhonen; Sagor; Lignite of Bonn.	Develier; Schangnau; Radoboj; Rhön.	Petit Mont, Lausanne; St. Gallen.	Œningen; Schrotzburg; Parschlug; Senegaglia.
Andromeda vacciniifolia, *Ung.*	Sotzka; Taurus ...	Monod.	Mönzlen	.....	.....
—— reticulata, *Ett.*	Hempstead; Hæring; Sieblos.	.....	.....	.....	.....
Echitonium cuspidatum, *Hr.*	.....	Manosque	.....	.....	Locle.
Gardenia Wetzleri, *Hr.* ..	.....	Salzhausen; Samland.	Rhön; Günzburg; Ruckers.	.....	.....
Nymphæa Doris, *m.*	Hempstead	.....	.....	.....	.....
Eugenia Hæringiana, *Ung.*	Hæring; Sieblos; Reut.	Ralligen	Lausanne; Calvaire; St. Gallen; Rhön.	Petit Mont, Lausanne; Turin.	.....
Celastrus pseudo-ilex, *Ett.*	Hæring	.....	Rhön	.....	Locle; Œningen; Hohen Krähen; Bischofsheim.
Carpolithes Websteri, *Br.*	Hempstead	Rochette; Conversion; Westerwald; Salzhausen; Laubach; Cadibona.	Rhön; Eisgraben; Zeche Einigkeit; Kaltennordheim.	.....	.....

A glance at this Table will at once satisfy us that the lignites of Bovey must be referred to the Lower Miocene division, and to the Aquitanian stage of it. It is true that nine of the species are found also in the Upper Miocene of other places, but these are all species which occur also in the lower stages, and which had a very extensive distribution both in time and space. Twelve species have been observed in the Mayencian and sixteen in the Tongrian stage; but nineteen have been identified in the Aquitanian stage in various localities. Certain species (*Palmacites Dæmonorops*, *Quercus Lyelli*, and *Nyssa europæa*) are not yet known in other districts as belonging to any but the Aquitanian stage; two (*Andromeda reticulata* and *Nymphæa Doris*) are known only in the Tongrian; others (*Pecopteris lignitum*, *Sequoia Couttsiæ*, *Dryandroides hakeæfolia*, and *D. lævigata*) only in the Tongrian and Aquitanian.

In this conspectus we have omitted the doubtful species (*Phragmites Œningensis*, *Dryandroides Banksiæfolia*, *Eucalyptus oceanica*, and *Pterocarya denticulata*). Should these be established by specimens in a better state of preservation, no disturbance would ensue to the above result, inasmuch as the *Phragmites* reaches back to the Lower Miocene, the *Eucalyptus* and *Dryandroides* belong to the Tongrian and the Aquitanian, the *Pterocarya* to the Aquitanian.

If we compare the Bovey flora with the several Continental floras, we shall find a great coincidence between it and that of Salzhausen in the Wetterau. A couple of species, viz. *Palmacites Dæmonorops* and *Nyssa europæa*, were previously known only from that district, while others, as *Pecopteris lignitum*, have been rarely found in other localities. With the Aquitanian stage of the Swiss Molasse (Hohe Rhonen, Ralligen, Monod and Rochette) Bovey has eleven species in common,—all species which occur in other parts, but two of them (*Dryandroides hakeæfolia* and *D. lævigata*) are especially frequent in Switzerland.

Of the French tertiary floras, it approximates most to that of Manosque in Provence. Here, as at Bovey, the most frequent fern is *Pecopteris lignitum*; and here also are found *Cinnamomum lanceolatum*, *Daphnogene Ungeri*, *Echitonium cuspidatum*, and *Dryandroides lævigata*. The water-lily of Bovey is probably one with the *Nymphæa calophylla*, Sap., of Manosque; but this cannot be determined, as we have only the leaves in the latter case, and the seeds in the former.

In the composition of the soft clay that contains the plants in the 26th bed at Bovey, and in the mode of their deposition in the same, there is great resemblance to the clays of Samland near Königsberg. A further connexion may also be traced through *Gardenia Wetzleri*.

It is remarkable that Bovey has no species in common with Iceland, although the tertiary flora of Iceland belongs to the same period, and two of its species (*Corylus MacQuarrii*, Forbes, and *Platanus aceroides*, Gp.) extend into Great Britain, having been found in Mull, in the Miocene of Ardtun Head. Even the genera are distinct, with the exception of two, *Sequoia*, and *Quercus*, which genera have each a single but distinct species in Iceland and in Bovey. The Bovey flora has a much more southern

character, corresponding entirely with that of the Lower Miocene of Switzerland. Bovey had three species of cinnamon, one laurel, evergreen fig-trees, one palm, and large ferns, thus manifesting a subtropical climate.

If we compare the Bovey flora with that of the Eocene beds of the Isle of Wight, we find certainly some points of connexion, but, on the whole, an essentially different character. As connecting points, we may observe that one species (viz. *Laurus primigenia*, Ung.) is common to Alum Bay and Bovey, and, moreover, that the genera *Quercus*, *Ficus*, *Dryandroides*, *Daphnogene*, and *Sequoia* appear in both places, although differing in species. The fact of only one species being found in common at so short a distance —that in the Eocene formations of the Isle of Wight the highly characteristic Cinnamon and Lastræas are wanting—above all, the fact that Bovey has many more species in common with the more remote Miocene formations of the Continent than it has with Alum Bay and Bournemouth, satisfies us that it belongs to a different horizon*.

In this summary we have noticed only the species already known. Among the new species, however, of which I have described twenty-six, several interesting forms are found. The first place belongs to the *Sequoia Couttsiæ*, m., a Conifer, which we can illustrate by branches of every age, and by the cones and seed. It supplies a highly important link between *Sequoia Langsdorfi* and *Sequoia Sternbergi*, the widely distributed representatives of *Sequoia sempervirens*, Lamb., and *Seq. gigantea*, Lindl. (*Wellingtonia*), which latter species are at present confined to California.

Of great interest also are two species of *Vitis*, of which the grape-stones lie in the clays of Bovey. They belong to different species from the tertiary vine of the Continent (*Vitis teutonica*, A. Br.); but it is not improbable that they may be identified with that of Iceland (*Vitis islandica*, m.), though we must leave this indeterminate for the present, as we have obtained only the leaves from Iceland, and only the grape-stones from Bovey. The three remarkable species of fig, the seeds of three new species of *Nyssa* and two of *Anona*, one new water-lily (*Nymphæa*), and many highly ornate *Carpolithes*, are important additions to our knowledge of tertiary plants.

If from the relics of Bovey plants, which are still far from numerous, we attempt to represent the vegetation of Bovey as it existed in the tertiary period, we shall have to sketch it somewhat in the following manner:—The woods that covered the slopes which surrounded the beds of lignite consisted mainly of a huge coniferous tree (*Sequoia Couttsiæ*), whose figure resembled in all probability its highly admired cousin the *Sequoia* (*Wellingtonia*) *gigantea*, Lindl., of California. It had just the same graceful slender appearance in its vernal shoots, thickly studded with leaflets; and the similarity continued in the older shoots and branches, which were clothed with scales. But it presented a distinct character in its shorter leaves, which were even more closely appressed to the shoots, and in its smaller cones. The leafy trees of most frequent occurrence were

* I received lately from Mr. Pengelly a collection of plants from the Tongrian stage of Hempstead (Isle of Wight); it contains four Bovey species, viz. *Sequoia Couttsiæ*, *Andromeda reticulata*, *Nymphæa Doris*, and *Carpolithes Websteri*.

the cinnamons (*Cinnamomum lanceolatum* and *C. Scheuchzeri*) and an evergreen oak (*Quercus Lyelli*, m.) like those which now are seen in Mexico. The species of evergreen fig were rarer, as were also those of *Anona* and of *Gardenia*. The trees of the ancient forest were evidently festooned with vines, beside which the prickly Rotang-palm (*Palmacites Dæmonorops*) twined its snake-like form. In the shade of the forest throve numerous ferns, one species of which (*Pecopteris lignitum*) seems to have formed trees of imposing grandeur; besides which there were masses of underwood belonging to various species of the genus *Nyssa*, which is at present confined to North America. On the surface of the lake in which were formed the deposits of clay and sand that lie between the lignite-beds, were expanded the leaves of those water-lilies the ornate seeds of which are preserved for our examination.

If we inquire further how far the plants help us to a definite view of the course of events by which these lignite-beds were formed, our conclusions will be somewhat of the following kind:—

It is highly probable that at the period of the Lower Miocene the Bovey basin was occupied by an inland lake. The entire absence of freshwater shells, and indeed of aquatic animals generally, is certainly very extraordinary; and so is the absence of fruits of *Chara*, which abound elsewhere in Miocene freshwater deposits; the *Nymphæa* seeds, however, afford positive proof of fresh water. We must not omit to notice that the parts of the basin hitherto explored, and the only parts which are accessible to investigation, lie at a great distance from the hills. Accordingly they were far from the bank, more in the middle of the lake, and, in the case of the lower beds, at a considerable depth. This explains the absence of bog plants, so numerous in other instances, as well as the absence of mammalian relics. These would not have drifted so far out into the lake, and probably they are to be found on the edge of the lignite formation, where the vegetation also may be expected to present a somewhat different character. The lignite-beds of the under series consist almost entirely of tree-stems (probably belonging in great measure to *Sequoia Couttsiæ*); these alternate with masses of a brownish-black clay, the dusky colour of which has doubtless been produced by the decomposition of the softer portions of the plant. No leaves offer themselves for recognition, but here and there twigs and seeds of *Sequoia Couttsiæ*, and little fruits, as *Carpolithes Websteri* and *C. nitens*. The tree-stems, which are here piled one over the other in huge masses (none of them stand upright), and which every here and there stretch their branches and roots in the layer of clay which has covered them up, have apparently been floated hither, not only from the immediate circuit of hills, but doubtless also from greater distances. Such a mass of timber could hardly have been furnished by the former. Accordingly we learn from the structure of these lignite-beds that they did not originate in a tertiary peat-deposit, but from a colluvies of wood uniting in a lake; and hence they differ widely from those of Paudèze, of Hohe Rhonen, of Käpfnach, and other localities of Switzerland. At the same time the lignites of Bovey must have taken a long period in the process of formation, as the repeated alternations of clay-beds sufficiently show.

When a mass of timber and mud had been deposited in the bottom of the Bovey lake, some natural disturbance (whether owing to extensive landslips falling into the lake, or to the river undermining its banks) must have occasioned the contribution of a mass of quartzose sand, which thickly covers the under set of lignites, and which must at the time have helped largely to fill up the lake. Immediately above it lies a soft clay with numerous leaves of plants (the 26th bed), just as they were drifted together from the woods in the fall of the year. It seems, then, that this bed was formed in autumn, and that the plants it contains are due to the driftings of that season; in further confirmation of which, is the frequent recurrence of the seed and ripe cones of *Sequoia Couttsiæ*. Higher up follows the bed with the fern-rhizomes, among which occasionally can be recognized the pinnules of *Pecopteris lignitum*, which, somewhat higher up, amidst the branches of the *Sequoia*, appear in great abundance, being here and there compacted together in dense masses.

Above this bed come strata of clay and comparatively inconsiderable deposits of lignite, which last were all formed from the collection of wood and plants drifted to the spot.

As this Lower Miocene formation is immediately succeeded by quartzose sand with White Clay, we have here a great hiatus. Either the Middle and Upper Miocene, as well as the Pleiocene periods, must have passed without the formation of deposits in this place, or the latter must have been removed during the Diluvial period.

B. *The White Clay.*

While the lignites and their alternating clays at Bovey present us with a vegetation which is subtropical, the plants of the White Clay exhibit a totally different character, and must have had their origin in a period altogether distinct. The collection of Mr. Pengelly contains four species from this formation—three of *Salix* and one of *Betula*; and, what is the most remarkable, none of these appear to me to differ from species now living. The little birch-leaves are not to be distinguished from those of *Betula nana*, Linn., nor the willow-leaves of one species from those of *Salix cinerea*, Linn.; while those of a second species come very near *Salix repens*, Linn., and also resemble strongly those of *Salix ambigua*, Ehrh. So variable is the form of these leaves, that it is hard to fix the species with positive certainty. At all events these leaves prove to us that those white clays must be much more recent than the lignite deposit; while the presence of *Betula nana*, Linn., which is in the highest degree remarkable, is conclusive for a diluvial climate, that is, a colder climate than Devonshire has at the present day; for this dwarf birch is an Arctic plant, which has no British habitat south of Scotland, and which occurs in Mid Europe only on mountains and subalpine peat-mosses. The evidence of the willow-leaves is to the same effect, indicating that at this period Bovey was a cold peat-moor. We may remark that *Salix cinerea*, Linn., is one of the most prevalent species of the diluvial travertine of Kannstatt.

I. *Descriptions of the Miocene Species of Plants.*

I. CRYPTOGAMÆ.

I. FUNGI.

1. Sclerotium, Tode.

1. Sclerotium Cinnamomi, m. (Plate LXVII. fig. 17; fig. 19, magnified; diameter magnified, 19 *d*.)

Scl. perithecio orbiculato, duro, plano, margine elevato.

On the leaf of *Cinnamomum Rossmässleri* there are several flat circular umbos. They are 1 millim. in diameter. They are quite smooth and flat in the centre, and surrounded by a very sharp edge.

They very much resemble *Sclerotium pustuliferum*, Heer, which is often found on *Quercus neriifolia* in Oeningen. Of the living species, *Scl. pustula* may be compared with it. Rossmässler has figured a closely resembling, but somewhat larger fungus, in his 'Beiträgen zur Versteinerungskunde,' taf. 8. fig. 27.

2. Sphæria, Hall.

2. Sphæria socialis, m. (Plate LXV. fig. 13, *c*; fig. 13, *c c*, magnified.)

Sph. peritheciis congregatis, minutissimis, orbiculatis, ostiolo rotundato pertusis.

In the 17th bed at Bovey.

There are many circular and convex little bodies close together on a leaf of *Dryandroides lævigata*, Heer. In the centre they are furnished with a pretty large aperture.

3. Sphæria lignitum, m. (Plate LV. fig. 1; figs. 2 & 3, magnified.)

Sph. peritheciis gregariis, liberis, conicis, nigris, apice nitidis, papillatis, ostiolo minuto, orbiculato.

I found this *Sphæria* on the bark of several branches, which perhaps belong to *Sequoia Couttsiæ*. They were lying in the 26th bed, beside some young branches of *Sequoia*. The perithecia form little black warts, which are clustered together in great numbers; the largest $\frac{1}{3}$ millim. in diameter; many of them are much smaller, and appear as black points. The largest of them are slightly conical, and furnished on the top with a very small though distinctly separated cicatricule. When this cicatricule falls away, a small aperture is left. In many of them a transverse slit has originated near the base, and the upper part of the perithecium has fallen away; thus we have a large aperture, surrounded by the pretty thick coat of the perithecium.

This belongs to the group of *Sphæriæ pertusæ*, Fries (Systema Mycolog. ii. p. 460), and has a great resemblance to *Sphæria umbrina*, which, however, is much larger and flatter.

II. FILICES.

1. Lastræa, Bory, Alex. Braun. (*Phegopteris*, Mettenius.)

4. Lastræa (Goniopteris) Stiriaca. (Plate LVI. figs. 12–15.)

L. fronde pinnata, pinnis linearibus, prælongis, grosse crenatis serratisve, nervis secundariis e nervo primario angulo subacuto egredientibus, pinnatis, nervis tertiariis utrinque plerumque 6–7, curvatis, subparallelis, angulo acuto egredientibus, soriferis; soris rotundatis, biseriatis.

Heer, Flora Tertiaria Helvetiæ, i. p. 31; iii. p. 151; pl. 6, 7, 143, figs. 7 & 8.

Polypodites stiriacus, Unger, Chloris Protogæa, p. 121, pl. 36.

This is the tertiary fern which has the widest distribution. It appears rarely in the Upper Molasse, however (on the Albis, in Parschlug and Sarzanello), but very often in the Aquitanian stage of the Lower Miocene formation—thus at Monod, the Paudèze, Hohen Rhonen, &c., in France at Ménat, and in Italy at Cadibona. Several portions of leaves have been found at Bovey, the determination of which is undoubted. The leaf figured in fig. 15 represents a pinnule in almost its whole length; the other figures represent parts of leaves, the nervation of which is well preserved (Plates LVI. fig. 12; LVII. fig. 8). The specimen Plate LVI. fig. 14 is a portion of a leaf with the rachis, on the side of which the pinnules are attached. The pinnule is long and narrow, with parallel sides, deeply toothed, the teeth bent towards the apex; their long side forms an arch, the sinus is acute. The principal nerve of the pinnule is strong, the secondary nerves are fine, springing at acute angles and forming a slight arch; from each secondary nerve spring, on the inner side five or six, and on the exterior side six or seven, but seldom eight, tertiary nerves. They are strongly bent upwards, and united exactly in the same manner as in the specimens I have described in the 'Flora Tertiaria Helvetiæ' (vol. i. p. 31). At Bovey, hitherto, only sterile leaves have been found, whilst Monod has furnished pinnæ covered with sori (cf. Plate LVI. fig. 13). The sori are in the middle, or a little outside the middle of the tertiary nerves; they are round, small, and ranged in two lines, converging towards the apex. We see, from the specimens discovered at Monod, that this species was a very large one. The leaves attained probably a length of 3 feet and a diameter of at least 1 foot. The pinnules are very distant from each other at the base of the leaf, whilst above they approach and get gradually shorter. Most of the specimens are from the 17th bed of Bovey, I saw, however, one in the clay of the 26th bed.

Lastræa Stiriaca most resembles *L. prolifera*, Kaulf. (*Phegopteris prolifera*, Metten.), of tropical America, and belongs to the genus *Lastræa* (div. *Goniopteris*), as Alex. Braun has established it (cf. Flora Tertiaria Helvet. i. p. 30, and iii. p. 150).

5. Lastræa Bunburii, m. (Plate LXIII. fig. 1, *b*; magnified, *c*, *d*.)

L. fronde pinnata (?), pinnis linearibus, apicem versus angustatis, argute serratis, nervis secundariis flexuosis, e nervo primario angulo subacuto egredientibus, pin-

natis, nervis tertiariis utrinque 2–4, subflexuosis, curvatis, angulo acuto egredientibus.

Only a portion of a leaf, of 71 millims. in length; it occurred in the clay of the 26th bed. At the base it was probably 19 millims. in diameter; towards the apex it gradually tapers; therefore it must probably have had a long apex, which however is not preserved. It very much resembles the former species, but differs by the tapering form, the smaller and very acute teeth, and the fewer tertiary nerves, which are undulated. A comparison with fig. 4, pl. 8 of the 'Flora Tertiaria' shows that it is not the exterior part of the former species. It approaches more to *L. helvetica*, Hr. (Flora Tertiaria, i. p. 33, iii. p. 151), in the tapering of the pinnules, notwithstanding the fewer tertiary nerves and the undulated secondary nerves. It differs from *Aspidium dalmaticum*, Ett., in the smaller teeth, and fewer tertiary nerves.

The margin is provided with very small and sharp teeth, which are very much bent towards the apex. The secondary nerves are thin, strongly undulated, and have on the under side mostly four, sometimes but three, on the upper one two or three tertiary nerves, which are also undulated. The lowest one is united with the lowest of the next secondary nerves, and forms with it a triangular acute areole, out of which springs a branch that advances to the next sinus. A little higher it is joined by two united tertiary nerves, also at an acute angle, and immediately under the sinus another one. This nerve directed to the sinus is also undulated.

2. Pecopteris, Br.

6. Pecopteris (Hemitelia?) lignitum, Gieb. (Plate LV. figs. 4–6; LVI. figs. 1–11; LVII. figs. 1–7, magnified.)

P. fronde pinnata, pinnis linearibus, longis, apice valde attenuatis et acuminatis, basi plerumque breviter petiolatis, profunde inciso-serratis, nervis tertiariis furcatis, inferioribus valde curvatis, sinum attingentibus.

Pecopteris lignitum, *P. crassinervis*, *P. leucopetræ* et *P. angusta*, Giebel, "Paleontolog. Untersuchungen," Zeitschrift für die gesammten Naturwissenschaften, 1857, p. 305, pl. 2. fig. 2.

Aspidium lignitum, Heer, Beiträge zur nähern Kenntniss der sächsisch-thüringisch. Braunkohlenflora, p. 424, pl. 9. figs. 2 & 3.

Aspidium Meyeri, Ludwig (non Heer!), Palæontograph. viii. 2. p. 63, pl. 12. fig. 3.

This is the commonest fern at Bovey; it and *Sequoia Couttsiæ* are the plants most commonly met with in this locality; the petioles and pinnules are heaped up in the 17th and 26th bed. They are only separated by thin layers of clay. On dissolving this, one is able to take the leaves out of it and preserve them in fluid (spirit, glycerine, water). They decompose in the air.

This species had a large distribution in the tertiary period, but is confined to the

Tongrian and Aquitanian stages. It has been found at Weissenfels in Saxony, at Salzhausen and Münzenberg, at Thôrens in Savoy, and at Manosque in Provence.

Hitherto no perfect leaves or pinnules have been found at Bovey, but so many portions of pinnules that one can easily put together the entire pinnule, as we have tried to do in Plate LVI. fig. 8. The pinnule is in length 173 millims., its extreme breadth 21 millims.; it gradually tapers towards the apex, and forms a long sharp point (Plate LVI. figs. 2–4, and magnified fig. 1). The pinnule is also narrower at the base than in the middle; at least several pieces evidently belonging to the base are narrower than those from the middle of the pinnule (fig. 5). The pinnule is shortly petioled, and has often unequal sides at the base. There are many such pinnules around a finely striated rachis; portions of which latter common rachis are often found (cf. Plate LV. figs. 5, 4 *a*, & 8) between the pinnules, and in several cases I have seen the lateral pinnules attached.

The pinnules are of a strong, almost leathery consistence, and, examined with a lens, they appear to be finely punctate. Their margin is deeply toothed, the broad portions in the middle of the pinnule are nearly pinnatifid, the teeth on the outer margin smaller, and closer together. All these teeth are strongly bent towards the apex; the long side forms a strongly-curved arch; they are entire, and provided at the tip with a distinctly separated little tooth. The midrib is pretty strong; the secondary nerves spring at the base of the leaf in slightly acute angles, and in more acute ones in the upper narrower part of the pinnule. They are mostly more or less curved, and on each side they send forking tertiary nerves, on the upper part (nearer the tip) mostly one or two less than on the lower one. The broad pieces of pinnules have on the lower side seven or eight tertiary nerves; the number lessens nearer to the tip, as the pinnules gradually taper (we count there 6, 5, 4, 3, 2), and quite near the tip they are undivided (fig. 1). Each of the tertiary nerves soon divides into two branches, which do not again divide; only the exterior ones remain entire. Those tertiary nerves are everywhere equally strong, and sometimes the fourth or fifth advances to the margin, whilst the following one is again forking. The lowest ones are very strongly curved, and enter the sinus always between two teeth. The lowest tertiary nerves do not generally join the nerve of the neighbouring pinnules (Plate LVII. figs. 1, 4 & 5), or only in the sinus, forming a very acute-angled triangle (figs. 3 & 7). In some cases they unite like *Goniopteris*, already a little lower (Plate LVII. fig. 2), forming several very acute-angled arches. The tertiary nerves mostly spring from the secondary; but sometimes a fine forking nerve immediately springs from the principal nerve (Plate LVII. figs. 1–5), and runs to the sinus of the teeth.

A portion of a leaf very different in the nervation is figured in Plate LVII. fig. 6 (magnified). The tertiary nerves spring at very acute angles; they are very numerous, and some of them are twice forked. The teeth seem to have been narrower and longer. This fragment may belong to another species, but is too imperfect to pronounce any

opinion upon. Beside the pinnules of the leaves, we often find at Bovey circinate young shoots of ferns (Plate LVI. figs. 9, 10 & 11), which probably belong to the species in question, as being the commonest one.

Professor Giebel, who first established this species, has given it four names: his *Pecopteris leucopetræ* represents the apex of the leaf, *P. angusta* a portion of the pinnule a little below the apex, where the tertiary nerves spring at acute angles, and *P. lignitum* and *P. crassinervis* the broader lower part of the pinnule.

Ludwig has confounded this species with *Aspidium Meyeri*, Heer. The portion of a leaf from Münzenberg, figured by him in pl. 12. fig. 3 of the 'Palæontographica,' entirely differs from *A. Meyeri*, in the shallower incision and different nervation. It belongs to *P. lignitum*. It seems to me that the portion of a leaf figured by him in pl. 10. fig. 2, belongs to another species.

I have formerly assigned this fern to the genus *Aspidium*, because the secondary nerves are usually forked, and the tertiary nerves often jointed like *Goniopteris*; but a close examination of the numerous and well-preserved fragments from Bovey has convinced me that they do not belong to *Aspidium*. The pinnules had a hard, nearly leathery structure; and the peculiarly curved lower tertiary nerves, which run in large arches, differ from *Aspidium*, and very much remind one of *Hemitelia*. The tertiary nerves of the Hemitelias are most of them jointed by small nervules; but still there are species in which this is not the case (ex. gr. *H. integrifolia* and *H. speciosa*), and in *H. Karsteniana* (cf. Mettenius, Icones Filicum, pl. 29. fig. 2) there is a variety the nervation of which has more likeness to that of *Pecopteris lignitum* than to any other species of fern known to me; therefore the species in question probably belongs to the genus *Hemitelia*. It may, however, be better in the meanwhile to preserve the name *Pecopteris* till the fruits are found, which certainly will be soon, this species being so common at Bovey. I have, however, sought in vain for sori amongst many hundreds of pinnules. Sometimes little round spots are seen which look like sori (Plate LV. fig. 4 *d*); but a careful examination shows that they are accidental markings, some of them upon the tertiary nerves, and others beside them.

In the 25th bed at Bovey (rarely in the 17th) we often find large rhizomes quite covered with petioles, which, I suppose, for the following reasons, to belong to *Pecopteris lignitum*.

1. In several pieces, I found between the petioles the pinnules of *Pecopteris lignitum*, though not attached.

2. In the lignites of Salzhausen quite similar rhizomes are found with pinnules of *Pecopteris lignitum* (cf. Ludwig, in the 'Paleontographica,' viii. p. 64, pl. 10. fig. 3); therefore Ludwig has compared it with this species (his *Aspidium Meyeri*).

3. The petioles are striated in the same manner as the petioles which are so often lying between the pinnules of *Pecopteris lignitum*, and which undoubtedly belong to one plant, as in some cases I saw them attached (Plate LV. fig. 4).

4. The rhizomes and the petioles are mostly curved towards one side; therefore the

rhizomes probably lay horizontally on the earth, and the leaves arched upwards, as we see in existing ferns.

The stems, and the petioles which cover them, are converted into coal; therefore a microscopic examination is not possible. The considerable thickness of the organs surrounding and covering the stems shows us that they are petioles, and not leaves. Though they are very much compressed, the thickness of the mass of coal is nearly always several millims.

The large specimens remind us directly of the pinnated leaves of palms (Plate LVIII.). On examining them minutely, we see that the supposed pinnules are not fastened in two rows on the rachis, but that they are placed around it spirally; therefore they cannot be pinnules of leaves; they are organs fastened on a stem; and as they are tapered at the base, and inserted on the stem with a tapering but not sheathing base, they cannot at all events be the leaves of a monocotyledonous plant. The leaves of ferns are inserted in that manner on the stem, and taper also sometimes towards the base. In most of the Aspidieæ, Asplenieæ, and Cyatheæ the petioles are continuous with the stem; they remain after the withering of the leaves, and form a thick and dense cover over the rhizome, as they do in the Bovey plant. It is remarkable that roots are seldom seen on these rhizomes; but in several specimens thread-like bodies can be seen between them, which probably were fibrils; and there are, further, some specimens which indicate that the numerous fine undulated striæ, which at some places are lying in heaps, are probably hairy scales which have covered the petioles.

The largest specimen is 7½ decim. long and 2 decim. broad. It is pretty strongly curved. The petioles are lying in heaps one upon another, and therefore must have covered the stem. In some specimens the stem is denuded here and there. It is quite converted into coal, and it is therefore as impossible to examine its anatomical structure as that of the petioles. These are of a considerable length, and always irregularly broken; their length therefore varies. I have collected great numbers of specimens at Bovey, and hoped to have been able to find the connexion of the petioles with the pinnules of *Pecopteris*, but was unsuccessful, though these rhizomes are in heaps in the 25th bed. The petioles gradually taper towards the base, which is rounded; they never sheath. Many specimens distinctly show that the petioles are not distichous, but are imbricated all round the stem. They are compressed, but the edges are defined.

At the same place there are portions of rhizomes provided with the cicatricules of roots (Plate LVIII. fig. 3). These are orbicular, 3 millims. in diameter, and consist of an elevated margin, surrounded by an orbicular depression, or, instead of this, they present a central wart, evidently originating from the central fibre. They are in pretty large numbers together, without being ranged in fixed order. The stems of living ferns have similar cicatricules of roots. The *Stigmaria*? of Altsattel, according to Rossmässler*, probably represents also a portion of the stem of a fern with the cicatricules.

* Beiträge zur Versteinerungskunde, pl. 12. fig. 58.

7. Pecopteris Hookeri, m. (Plate LVIII. fig. 3.)

P. pinnis elongato-lanceolatis, anguste serratis, nervis secundariis furcatis.

I have seen only a drawing (Plate LVIII. fig. 3) which Mr. Fitch has made. He assured me that the nervation and the natural size of the leaf were truly represented. The leaf seems to be lost; for it could be found neither in London nor at Mr. Pengelly's, at Torquay. It consists of a pinnule*, the base and point of which are wanting. It is toothed, the teeth sharp and bent towards the apex, the secondary nerves partly alternate, partly opposite, each of them divided into a simple fork. The branches of the fork run to the teeth.

II. PHANEROGAMÆ.

A. Gymnospermæ.

Order CONIFERÆ.

Fam. Abietineæ, Rich.

1. Sequoia, Endl.

8. Sequoia Couttsiæ, m. (Plates LIX., LX., LXI.)

S. ramis alternis, rarissime verticillatis, ramulis junioribus elongatis, gracilibus; foliis squamæformibus, imbricatis, subfalcatis, medio dorso costatis, basi decurrentibus; strobilis globosis vel subglobosis; squamis peltatis, medio brevissime mucronulatis, rugosis; seminibus alatis, compressis, nucleo paulo curvato.

This and *Pecopteris lignitum* are the commonest plants of Bovey, and their stems certainly contribute the greatest amount of lignite. Larger and smaller branches of this tree occur in the 17th and 26th beds of the clay. Entire cones (as represented in Plate LIX. figs. 1, 14, 16 & 18), seeds, and scales of cones have been found in great numbers. It is certain that the cones and seeds belong to one plant; for they not only agree with those of *Sequoia*, but in several cases I have seen the seeds lying in their natural position under the cone. But it might be questioned if all those branches the principal forms of which are represented in Plates LIX. and LX. belong to this same tree, because the young twigs so closely resemble those of *Glyptostrobus europæus*. A very minute comparison, however, of many specimens has persuaded me that this is not the case, and that all the figured branches and cones belong to one plant. In comparing the leaves of the twigs which bear the cones (Plate LIX. figs. 14, 16 & 18), we see that their form agrees with the loose twigs. As the principal character of these leaves, we may observe that they are nearly always somewhat falcate (cf. Plate LX. figs. 14–20). This is not the case with *Glyptostrobus europæus* (cf. Plate LX. fig. 49, magnified fig. 49 *b*,

* This form very much reminds us of *Lastræa Bunburii*, the nervation of which is however quite different.

where a twig of *Glyptostrobus* of the Hohe Rhonen is represented for comparison). The adnate scale-like leaves are straight in *Glyptostrobus*, or only somewhat curved outwards and obtuse, as in *Glyptostrobus heterophyllus*, Br. The spreading leaves are often provided with an acute and usually straight point, and, but seldom, a little curved; when this is the case, they have at all events a great likeness to our *Sequoia*.

As we have the branches, fruits, and seeds of this tree, the determination of the genus is undoubted. It resembles in all its principal points *Sequoia*, Endl. It has decurrent leaves, globose cones with peltate scales. They are provided on the surface with wrinkles radiating from a small mucro.

Several flat-winged seeds are lying under the scales. The scales and seeds very much resemble those of *Sequoia sempervirens*, Lamb., of California (cf. this cone, Plate LX. fig. 48, and the seeds of this species, fig. 47, magnified 47 *b*); but the nucleus of the seed is somewhat curved in the fossil species. The leaves are quite different, those of the sterile branches of *Sequoia sempervirens* being distichous and long linear, almost as in *Taxus baccata*, Linn. The *Sequoia Couttsiæ* approaches *S. gigantea* (*Wellingtonia*, Lindl.) in the form and position of the leaves, but differs in the much smaller cones. The Bovey species is in some measure intermediate between the two existing species.

In comparing the species of Bovey with the tertiary species of *Sequoia*, the *S. Langsdorfi*, Br., will be first taken into consideration. The cones are very similar (cf. Flora Tertiaria Helvetiæ, pl. 21. fig. 4 *d*, pl. 146. fig. 16; and Ludwig, Palæontographica, Band viii. pl. 15. fig. 1); but this species has the leaves of *S. sempervirens*. Our species still more resembles *S. Hardtii* *, the scales of the cones being of the same length and form, but Unger and Ettingshausen describe the cones as subconical, and the seeds as provided with a mucro; further, the leaves of the fertile twigs are more acute, and those of the sterile ones are linear and spreading. The Bovey species differs from *S. Sternbergi* (*Araucarites*, Gp.) in the much more slender twigs, and the different construction of the leaves. It differs from *S. Ehrlichi*, Ung., in the shorter leaves and the globose cones.

If we compare all the Sequoiæ now known, we have to place them in the following manner:—

1. *Sequoia gigantea*, Lindl.; California.
2. *Sequoia Ehrlichi*, Ung.; tertiary formation near Spital in Austria.

* *Cupressites Hardtii*, Goeppert, Monogr. der Fossilen Coniferen, p. 184.
Cupressites taxiformis, Unger, Chloris protogæa, p. 18, pl. 8. figs. 1–3, pl. 9. figs. 1–4.
Chamæcyparites Hardtii, Endl. Synopsis Conifer. p. 277; Ettingshausen, Flora von Haering, p. 35, pl. 6. figs. 1-21.
Endlicher and Ettingshausen have wrongly referred this species to *Chamæcyparis*; the leaves of which genus are opposite, and ranged in four rows round the branch, whilst they are alternate in *S. Hardtii*, as in *Sequoia*; the cones of *Chamæcyparis* are much smaller, and the seeds have a thicker nucleus, the base and point of which are not surrounded by the thin wing. This species has no doubt been referred to *Chamæcyparis* by Unger from a comparison with *Cupressus thurifera*, Humb. et Bonpl. (*Chamæcyparis*, Endl.).

3. *Sequoia Sternbergi*, Gp.*; has a wide distribution in the Miocene formation, from Senegaglia to Iceland.

4. *Sequoia Couttsiæ*, Hr.; Bovey.

5. *Sequoia Hardtii*, Gp.; Haering and Armissan.

6. *Sequoia Langsdorfi*, Br.; spread over the whole Miocene formation, in Italy, Germany, Switzerland, France, Isle of Mull, Greenland, Bear-lake River, Vancouver Island, from the Unga at the shore of Aleski, Russia near Orenburg.

7. *Sequoia sempervirens*, Lamb.; California.

The genus *Sequoia* probably begins in the cretaceous formation; for *Geinitzia* (*Cycadopsis*, Deb.) is so nearly related to *Sequoia*, that, according to Dr. Debey, it can scarcely be separated from this genus, and may be considered as the predecessor of it. This genus most abounded in the Miocene time; it was spread over the whole Continent as far as we know. In the present creation we have but two remains of this type, both found only in California. These two living species represent the two extremes of all the known forms. Of the fossil species, *S. Langsdorfi* especially approaches to *S. sempervirens*, and *S. Ehrlichi* and *S. Sternbergi* to *S. gigantea*. *S. Couttsiæ* is the intermediate species between these two principal types.

I now proceed to describe the Bovey specimens.

The annual twigs (Plates LX. figs. 9–20; LIX. and LX. figs. 7 & 8, magnified) are very slender, often of considerable length (figs. 14–16), without producing lateral twigs. The leaves cover the twigs like scales, which are mostly very close together (Plate LX. fig. 10); on the long twigs they are more distant. At the base of the young shoots they are always closer and shorter (fig. 7), a little more outwards they are more distant. The leaves are alternate, though sometimes two are nearly opposite, but never exactly so. All the leaves are decurrent at the base. The very short scale-like leaves are somewhat falcately curved (cf. Plate LX. fig. 13, magnified), and still more so are the leaves which are more distant from one another (Plate LX. figs. 14, 15 & 17). These leaves are

* I have already tried to show, in my 'Flora Tertiaria Helvetiæ,' iii. p. 317, note, that *Araucarites Sternbergi*, Gp., belonged to *Sequoia*. Massalonga has given, in his 'Specimen Photographicum,' pl. 21, a photograph of his *Araucarites venetus* of Chiavon. He said that the leaves and twigs were not different from those of *Araucarites Sternbergi*; he took it for a different species, because he thought, with Unger and Ettingshausen, that the cone presented under the name of *Araucarites Gœpperti*, St. (Sternberg, Pflanzen der Vorwelt, pl. 89. fig. 4; Goeppert, Fossile Coniferen, pl. 44. fig. 2), was to be referred to *A. Sternbergi*. But we have shown, in the 'Flora Tertiaria,' that there are no sufficient reasons for it; and the circumstance that cones are found, in Chiavon, on a twig which is not to be distinguished from *A. Sternbergi*, and also immediately beside similar twigs in Iceland (quite different from *A. Gœpperti*), confirms this opinion. The cone of Chiavon is much compressed, and lies in a lateral position, while the cones of Iceland represent the transverse section (as do the pieces represented by Sternberg, 'Flora der Vorwelt,' ii. pl. 57. figs. 1–3, as *Steinhauera subglobosa*, Presl, which, according to my opinion, belong to this species). The scales of the cones are small and in great numbers, and very different from *Araucaria*, while the cone figured by Massalonga has a great resemblance to that of *Sequoia gigantea*. The seeds represented as *Steinhauera* quite agree with *Sequoia*.

acuminate, and the point is curved outwards (Plate LX. fig. 14 *b*, somewhat magnified). Amongst the great number of twigs I have seen, there was only one with much longer linear leaves (Plate LX. fig. 12, magnified fig. 12 *a a*) than they commonly appear in *Sequoia Hardtii*. Twigs with such long leaves therefore must be very rare. The small portion of a twig which is represented in fig. 9 (magnified) forms the intermediate form of this leaf. The leaves are always rigid, and provided at the back with an elevated edge, which runs to the apex of the leaf. The biennial twigs (Plate LX. figs. 1 & 2) are much thicker and also quite covered with leaves, which are scale-like, applied to the stem; they are broader than the leaves of the annual twigs, and closer together at the base of the twigs. They show at different places the scars on which the alternate shoots have been fastened. I only saw one branch with whorled twigs (Plate LIX. fig. 13). The branches of three years (Plate LIX. figs. 9 & 11) are 5 to 6 millims in breadth. We see on them numerous cicatrices of branches, which indicate the insertion of the twigs. The leaves are nearly of the same size as those of the biennial ones; they are, however, not so close together; they are scaly, adhering to the twigs, and the epidermis is provided with many longitudinal wrinkles. These twigs are thicker at the base (Plate LIX. fig. 11). As there are many twigs found thus thicker at the base, they appear to have separated themselves very easily from the stem at the place of insertion. The leaves disappear on still thicker and therefore older twigs, and only small scars remain on the bark. Beside these branches of different ages, there are trunks which probably belonged to this tree.

The cones are solitary or in pairs (Plate LIX. fig. 14, restored fig. 15), on rather slender twigs quite covered with scaly leaves. They are globose (Plate LIX. fig. 16, restored fig. 17; fig. 14), or shortly oval (fig. 19), from 15 to 24 millims. in length, and from 15 to 17 millims. in breadth. The scales are peltate, the footstalk is short, and seems to be central (Plate LX. figs. 29, 30 & 33); the upper side is polygonal, but this form is not constant; in the middle is a very short mucro, from which originate several wrinkles that radiate to the margin; the surface is therefore pretty roughly wrinkled. Cones in which the scales are closed are rare (Plate LIX. figs. 14, 16 & 18). They must have been enveloped by the clay when still fresh. They are often spread open and the scales separated from one another, and the spaces filled with clay (Plate LX. figs. 27 & 28); or we have but solitary scales or portions of cones (Plate LX. figs. 29–35).

There are several seeds beneath every scale (Plate LX. fig. 25); they are also very often scattered between the twigs. The seed is usually 5 millims. long and $3\frac{1}{3}$ millims. broad, and flat; it is somewhat emarginate at the point of insertion, obtusely rounded and a little tapered towards the tip. The nucleus is somewhat curved and pretty flat. It is surrounded by a flat wing (Plate LX. figs. 37–41; fig. 41 *b*, magnified).

In the lignite of Bovey both small and very large pieces of resin are found, which were probably secreted by the *Sequoia Couttsiæ*.

The lignite of Bovey contains very large stems, the zones of which are mostly distinct and crowded; in several stems I could count a hundred of them. One can easily split

them longitudinally; but they become quite hard and brittle in the air, and crumble if cut. They are then brown or black. The microscopical examination did not give me satisfactory results. I certainly recognized the elongated woody fibres, but in most cases I was not able to distinguish the structure of their walls, which is very obscure. However, in some cases I saw pores, which are ranged in one row (cf. Plate LXXI. figs. 8 & 9), and, further, the medullary rays, which are formed from a single row of cells (Plate LXXI. fig. 8). There is no trace of spiral or reticulated vessels. The structure of the medullary rays and of the fibres proves it to be coniferous wood. As *Sequoia Couttsiæ* is the only coniferous tree hitherto found in the lignite-beds of Bovey, and was the commonest tree of that country, it is very probable that most of the wood belonged to it.

B. Monocotyledones.

Order I. GLUMACEÆ, Bartl.

Fam. I. Gramineæ, Juss.

1. Phragmites, Trin.

9. Phragmites œningensis, A. Br.? (Plates LXIV. fig. 1 *d*; LXV. fig. 13 *a*; and LXVIII. fig. 2.)

Phr. foliis latis, multinervosis, nervis interstitialibus tenuissimis.

Heer, Flora Tertiaria Helvet. i. p. 64, pl. 22. fig. 5, pl. 24.

Only some small parts of leaves; the determination is therefore uncertain. We observe very slender secondary nerves between the strong longitudinal nerves. We can count twelve of them, all equally strong, between two longitudinal nerves, while in *Phr. œningensis* the median nerve is always a little stronger. In the same layer (in the 17th bed of Bovey) there are also some indistinct remains of culms, which probably belong to these fragments of leaves; likewise the pieces figured in Plate LXVIII. fig. 2, which all represent horizontal sections of culms. Fig. 2 *a* represents the section of a a knot, where, as in *Phragmites communis*, we have a middle part, which appears as a circular umbo, and around it the wall of the culm.

2. Poacites, Br.

10. Poacites, sp. (Plate LXVIII. fig. 3.)

Bovey (Dr. Falconer).

It is a thin, finely striated grass-culm, on which we perceive a knot. It is $2\frac{3}{10}$ millims. in breadth. It is not sufficient for a more exact determination, but seems to prove that small grasses existed in that country.

Fam. II. Cyperaceæ, DC.

3. Cyperites, Hr.

11. Cyperites deperditus, m. (Plate LX. fig. 54.)

C. fructibus parvulis, ovatis, apice acuminatis, tenuissime striolatis.

In the 26th bed of Bovey; fragments only.

Under the name of *Cyperites*, I have comprised in my 'Flora Tertiaria' those remains (leaves, culms, and fruits) belonging to plants of the family of the Cyperaceæ which it is not possible now to refer to any genus. The fruits in question very much resemble those of *Carex*, and belong probably to this genus. They are like those of *Carex recognita*, Hr., from Rochette. The fruit is 4 millims. in length, and at the base 2⅔ millims. in breadth; it is there obtusely rounded, but tapered and acuminate at the apex. It is provided with very fine longitudinal striæ.

Order II. PRINCIPES, Linn.

(Palmæ.)

1. Palmacites, Hr.

12. Palmacites Dæmonorops. (Plates LXII., LV. figs. 7–15.)

P. spatha coriacea, longitudinaliter tenuissime striata granulataque, aculeata, aculeis crebris seriatim in lineis oblique transversis conjunctis, compressis, subulatis, rectis, simplicibus, binis, trimis, vel ad summum senis, adpressis; caudice gracili, aculeato, fasciculis vasorum rigidis, interne planis vel sulco exaratis.

Palæospathe Dæmonorops, Unger, Sylloge Plantar. Fossil. p. 9, pl. 2. figs. 9–12.

Chamærops teutonica, Ludwig, in Meyer's Palæontogr. viii. p. 86, pl. 20. figs. 2 & 3.

Pretty common in the clay of the 26th bed of Bovey.

Chiefly the prickles are found at Bovey. They are black as coal, brilliant, very thin, and taper to a fine point. Their length varies from 4 to 50 millims. The longest are only 3 millims. in breadth at the base (cf. Plate LV. fig. 13). They are flat, and provided with a very shallow longitudinal depression (Plate LXII. fig. 9 *b*, a specimen highly magnified), which in some cases becomes almost a furrow. There are mostly three of them together (Plates LXII. fig. 1, and LV. figs. 11 & 15), and the median one is the longest (Plate LXII. figs. 2, 10 & 11, magnified). Sometimes there are but two together, or they are single; or, on the contrary, there are four, five (Plate LXII. fig. 3), or more prickles forming a group. In many pieces I am persuaded that they are not fastened on the margin of an organ, but pretty regularly distributed on a plane surface. Therefore they cannot be simple prickles of the petioles of leaves, as of *Chamærops*, for which Ludwig has wrongly taken them, as I was convinced on looking at the pieces represented in Plate LXII. fig. 1, and still more when I washed them in water. We see then that the bundles of prickles are fastened on and pressed against a very finely

striated plane surface, which is provided with minute warts (Plates LXII. fig. 7, and LV. figs. 11 & 12). They are broader at the base. The form of these prickles, their position (mostly three together, and the median of them the longest), and their direction (all are directed forwards and pressed against the surface) agree so well with the organs represented by Unger from Laubach in the Wetterau, and by Ludwig from Salzhausen and Hessenbrucken, that we may be persuaded of their belonging to the same plant. Unger compares these prickles with those which appear on the spatha of *Dæmonorops*. We have indeed in *D. polyacantha*, Martius (Palmæ, pl. 160), and *D. melanochætes*, Blume (Martius, pls. 117 & 125), very similar flat prickles, which are broader at the base. There are often three together, the median one of which is also the longest. As at Bovey, these bundles of prickles are often fastened on a flat, spreading, finely striated organ, which is several millims. in thickness, which may be easily taken for a spatha. But it is quite unsuitable to found the name of the genus upon this spatha, and to describe this plant as *Palæospathe*, for we find the same prickles also attached to the stems. I have found at Bovey, in the 26th bed, the stem of a palm, on which such a bundle of prickles was attached. Unhappily it was ruined on the journey. On the contrary, several of these stems, which I collected in the same layer containing the prickles, have remained entire. Some of them are represented in Plate LV. figs. 7–10. They are from 15 to 17 millims. in thickness, and consist of a bundle of fibres which are converted into coal, and appear like brilliant coal-black threads. Each fibre (or bundle of vessels) is flat on the inner side, which is turned towards the centre of the stem, or furrowed longitudinally; on the outer side it is convex; it represents, therefore, on a transverse section, more or less, a half circle or a crescent. These fibres are in some pieces close together, and in others further apart; the latter are probably from the middle, and the former from the periphery of the stem. Some of the fibres attain a thickness of 1 millim., but many are much thinner. In many pieces these bundles of vessels form a stem (cf. figs. 8 & 9). Sometimes they are free, and appear like long black fibres scattered in the clay; or beside the united ones we see numerous scattered bundles (cf. Plate LV. figs. 7 & 10). These organs very much resemble the bundles of vessels which appear in the lignite of Käpfnach (*Palmacites helveticus*, Flora Tertiaria Helvetiæ, p. 94, pl. 40. fig. 1); but such thick pieces have not hitherto been found at Bovey. The stems were thin, and probably the petioles may have been so too. The construction of the bundles of vessels shows indeed that they belonged to a monocotyledonous plant, and confirms the conclusion derived from the prickles attached to the spatha.

I found at the same place several fragments of leaves (Plate LXVIII. fig. 1) which certainly belong to a monocotyledonous plant, and perhaps, therefore, to the species in question. They are broad portions of leaves, with numerous fine longitudinal parallel striæ of equal strength; nine of them occupy 1 millim. They are therefore very close.

Mr. Pengelly found a fruit at Bovey* which probably belongs to the plant in ques-

* I have seen only a drawing of this.

tion. It is oval (cf. Plate LX. fig. 50; magnified, figs. 51–53), 13 millims. in length and 10 millims. in breadth, and covered with scales. It resembles the fruit of the Rotang palm; and as the prickles and the construction of the stems point to these palms, we may combine these organs, and conclude that this palm grew at Bovey. In connexion with this I may mention that large pinnatifid leaves (cf. Flora Tertiaria Helvetiæ, iii. pl. 149), which belong to a Rotang palm, have been found at Oeningen. I have described them as *Calamopsis*. The palm of Bovey belongs perhaps to this genus; but I thought it better to place it in the collective genus *Palmacites*, which contains the different organs of palms which cannot yet be ranged in a fixed genus. These prickles have not been found at Oeningen up to the present time; and the petioles of *Calamopsis* are without prickles. Similar black prickles, however, appear in different genera of palms (for instance *Bactris*), but they are certainly most frequent in the group of the *Calameæ*, Kunth (*Lepidocaryinæ*, Mart.).

C. Dicotyledones.

Coh. I. *APETALÆ*.

Order I. AMENTACEÆ.

Fam. I. CUPULIFERÆ, Rich.

1. QUERCUS, Linn.

13. QUERCUS LYELLI, m. (Plates LXIII. figs. 2–9; LXIV. figs. 1–4; LXV. fig. 12 *b*; LXVI. figs. 1 & 2; LXVIII. figs. 4 & 5.)

Q. foliis subcoriaceis, petiolatis, lanceolatis vel oblongo-lanceolatis, basi attenuatis, margine undulatis, apice acuminatis, nervo primario valido, recto, nervis secundariis numerosis, curvatis, apice furcatis, ramulo superiore margini valde approximato.

Phyllites cuspidatus, Rossmässler, Beiträge zur Versteinerungskunde, p. 36, pl. 9. figs. 38 & 39.

It frequently appears in the 17th bed at Bovey.

Three forms are distinguishable:—1. narrow lanceolate leaves, which are strongly tapered at the base, and the margin of which is slightly undulated (Plates LXIV. fig. 1 *b*, *c*; LXIII. figs. 3 & 8); 2. narrow leaves, with almost parallel sides in the middle (Plate LXV. fig. 12 *b*); 3. broad leaves, which are distinctly undulated at the margin (Plate LXVI. figs. 1 *a* & 2; LXIII. figs. 5–7). This last form is the most frequent, and is to be considered as the typical. These leaves are of a pretty hard texture, but they seem to have been less leathery than those of *Q. furvinervis*. There are no entire leaves preserved; however, with the aid of the different pieces we can complete one. They were broadest in the middle, and gradually tapered towards the petiole and apex. In most of the fragments the petiole is not preserved. The piece represented in Plate

LXIII. fig. 9 shows us a petiole 14 millims. in length, in which it differs from *Q. furvinervis*. The pieces represented in Plate LXVIII. figs. 4 & 5 show us that the apex of the leaf was very long. The piece represented in fig. 5 had a very tapered apex. The broad leaves have a pretty strongly undulated margin (Plates LXIV. fig. 1 *a*, and LXIII. fig. 7, magnified 7 *b*) without forming teeth. The median nerve is strong and straight. Numerous secondary nerves spring from it at an angle of 50°. They are rather strongly curved, and reach nearly to the margin, where they fork, and the upper branch bends forward and, running parallel with the margin to the next following secondary nerve, joins it. The lower branch of the fork is very small and slender, or quite wanting in slightly undulated leaves, and at the places where the undulation is wanting. This course of the secondary nerves is very characteristic of our species, as of *Q. furvinervis* and *Q. undulata*. The areas are divided into secondary areas by continuous, sometimes forking nervules. A polygonal reticulation may be perceived in them, which encloses a still more delicate one (cf. Plate LXIII. fig. 7 *b*).

Rossmässler has described two forms of leaves from Altsattel as *Phyllites furvinervis* and *Ph. cuspidatus*. The latter differs from the former in the undulated margin (which is not toothed), and the long tapering point. As I also got from Weissenfels the toothed form with an elongated point, I formerly united *Ph. cuspidatus* with *Ph. furvinervis* (cf. Beiträge zur nähern Kenntniss der sächsisch-thüring. Braunkohlen-flora, von O. Heer; Abhandlungen des naturw. Vereins für die Provinz Sachsen und Thüringen, ii. p. 424), and I described the form with the narrow leaves as *Q. furvinervis cuspidata*. But as at Bovey there is found only the form with the undulated leaves, and as there is a petiole (which is not preserved with the leaves of Altsattel) which by its length gives us a new distinctive character for *Phyllites cuspidatus*, I have separated it from *Ph. furvinervis*. The name given by Rossmässler could not be retained, as there is already a *Quercus cuspidata*, Thunb. The principal distinction between *Q. Lyelli* and *Q. furvinervis* consists in the length of the petiole, and in the latter species having undulated leaves.

Further examination, and a comparison of more copious material, will show if these differences are specific or not. They belong, at all events, to the same type, which was very frequent in the Lower Miocene period, and of which similar species are still living in Mexico (for instance, *Q. xalapensis*, Thunb.). *Quercus undulata*, O. Weber* (Palæontograph. ii. p. 170, pl. 19. figs. 1, 2 *a* & *b*), is also a very similar species. In the undulated margin, and the manner in which the secondary nerves run, it is like *Q. Lyelli*; but the median nerve of this species is straight and much stronger, not undulated; the secondary nerves are more numerous, and spring at less acute angles.

I still doubt if the leaf represented in Plate LXIII. fig. 7 belongs to the species in

* The leaves (pl. 19. fig. 2 *a* & *b*) in Weber's 'Abhandlung' belong, according to my opinion, also to *Quercus undulata*, and are different from *Q. Gœpperti* (pl. 19. fig. 2 *c*), in which the leaf is rounded at the base. I may mention that the leaf which Ludwig (Palæontogr. viii. pl. 34. figs. 1–4) has represented as *Q. furvinervis*, belongs to another species.

question. The form and kind of tapering at the base agree, but it has more numerous and more crowded secondary nerves.

I found in the 26th bed at Bovey several fragments of bark which probably belonged to an oak, and therefore might belong to the species in question. The bark is very thick and corky, provided with deep longitudinal furrows, and in some places furrowed transversely (cf. Plate LXVIII. fig. 6).

Fam. II. Moreæ, Endl.

2. Ficus, Tournef.

I have already mentioned in my 'Flora Tertiaria' (ii. p. 64) that the leaves of many living species of fig-trees (I allude to the species which have leaves similarly shaped to *Ficus fulva*, Spr., *F. rubra*, Spach, *F. ferruginea*, Desf., and *F. phytolaccæfolia*, Hort. Berol.) have a granulated appearance and a rough surface due to numerous little warts which cover the epidermis, and that the tertiary flora of Switzerland also possessed two species, the leaves of which had the same rough surface. It is very curious that there are in the 26th bed at Bovey leaves which are granulated in this manner; and one of them is very near to *Ficus scabriuscula*, Hr. I therefore believe that I am not mistaken in ranging these three species under the genus *Ficus*. The following facts indicate that the granulation belongs to the leaf and not to the stone:—1. The stone certainly is finely granulated; but these granules are larger than the small points of the leaves, which can only be seen with the aid of a lens, and which are all of the same size; 2. they are regularly spread over the surface of the leaf; 3. they are on all the pieces of this species, but not on the leaves of other plants (e. g. *Cinnamomum lanceolatum*, *Daphnogene Ungeri*, and *Lastræa Bunburii*), which are lying in the same clay.

14. Ficus Falconeri, m. (Plates LXIII. fig. 1 *a*; LXIV. figs. 6 & 7; LXVI. fig. 4.)

F. foliis coriaceis, magnis, confertissime granulatis, elliptico-lanceolatis, apice longe acuminatis, nervis secundariis subtilissimis, remotis, valde curvatis.

The leaf represented in Plate LXIV. fig. 7 is the best preserved. The upper part is quite perfect, but the base is wanting. It is entire, and 12 millims. wide in the middle; it is gradually tapered towards the apex, forming a long narrow point. The secondary nerves are very delicate, and there are but few to be discovered with the lens. They are strongly curved, and form arches, which are far from the margin. The areas are divided by very delicate nervules, and filled up with a very delicate reticulation. The rigid points which cover the whole surface are very small, and only to be seen with a strong lens. Plate LXIV. fig. 6 is the point of the leaf, the secondary nerves of which are more distinct.

It is still doubtful if the leaf represented in Plate LXIII. fig. 1 *a* belongs to this species. It shows the same peculiar sculpture (cf. fig. 1 *a a*), and also very delicate secondary nerves; but they approach nearer to the margin, and are much less directed

towards the apex. This leaf is very like *Ficus obtusata*, Heer*, and belongs perhaps rather to this species; but as the specimen is incomplete, it is better to unite it with *Ficus Falconeri*. It may be that the areoles of the small areas are not so long (cf. fig. 1 *a a* magnified, and 1 *a a a* still more magnified) as those of *Ficus obtusata*. They are quite covered with little warts. The secondary nerves of the leaf in question are also very delicate, and united in strongly curved arches at the end. The areas are divided by means of delicate nervules into secondary areas, in which is the fine polygonal reticulation (fig. 1 *a a*).

15. Ficus Pengellii, m. (Plates LXV. figs. 7 & 8, and LXVI. fig. 3.)

F. foliis coriaceis, longe petiolatis, confertissime granulatis, ellipticis, basi apiceque attenuatis, nervis secundariis remotis, angulo acuto egredientibus, valde curvatis.

The leaf represented in fig. 8 shows the same peculiar sculpture as the former species (cf. fig. 8 *b*, where the portion of a leaf is magnified); it is more indistinct in the second leaf (fig. 7), which belongs to the same species. The species in question differs from the former one in the elliptical form of the leaf, which has no long point, and the acute angle of the secondary nerves. The leaf is broadest in the middle and equally tapered at both ends, so that the sides form pretty regular curved lines. The secondary nerves are delicate, springing from acute angles, strongly bent towards the apex, and thus form long arches. The principal areas are divided by means of delicate nervules into secondary areas, in which the polygonal areas are covered with very small rigid points that are only to be seen with the aid of a strong lens. The petiole is very long, and rather slender. It belongs to the same section as *Ficus phytolaccæfolia*, Hort. Berol.

16. Ficus eucalyptoides, m. (Plate LXV. figs. 3, 4 & 5.)

F. foliis coriaceis, lanceolatis, confertissime granulatis, basi apiceque attenuatis, nervis secundariis subtilissimis, valde curvatis.

This is another hard leathery shining leaf, but much smaller than that of the former species. It is broadest in the middle, and almost equally tapered towards both ends. It is doubtful if a petiole existed. Very delicate secondary nerves spring from the median nerve; they are jointed in strong arches. The surface is also covered with very delicate warts. It is like the leaf of *Eucalyptus oceanica*, Ung., in form, but differs especially in the surface, because *Eucalyptus* has quite a smooth leaf.

* Flora Tertiaria, ii. p. 65, pl. 82. figs. 5 & 6, pl. 100. fig. 14.

Order II. PROTEINÆ.

Fam. I. Laurineæ, Vent.

1. Laurus, Linn.

17. Laurus primigenia, Ung. (Plate LXV. fig. 6.)

L. foliis subcoriaceis, late lanceolatis, acuminatis, nervo primario valido, nervis secundariis tenuibus, sparsis, sub angulo acuto egredientibus.

Unger, Fossile Flora von Sotzka, p. 38, pl. 19. figs. 1–4.

Heer, Flora Tertiaria Helvetiæ, ii. p. 77, pl. 89. fig. 15; iii. p. 184, pl. 153. fig. 3.

In the 26th bed.

The leaf represented in Plate LXV. fig. 6 agrees very well with the leaf of the Hohe Rhonen, which is represented in pl. 153 in my 'Flora.' It is dark brown, rather hard, smooth and entire, and gradually tapered towards the base. The secondary nerves are at a distance from each other, strongly curved, and form long arches near the margin. The large principal areas are divided into secondary areas by fine nervules. The apex of the leaf is not preserved.

2. Cinnamomum, Burm.

18. Cinnamomum Rossmässleri. (Plate LXVII. figs. 17 & 18.)

C. foliis ellipticis vel oblongo-ellipticis, triplinerviis, nervis lateralibus acrodromis apicem attingentibus, nervatione in areis reticulata.

Flora Tertiaria Helvetiæ, ii. p. 84, pl. 93. figs. 15–17.

Phyllites cinnamomum, Rossmässler, Versteinerungen von Altsattel, p. 23, taf. 1. fig. 4.

Daphnogene cinnamomifolia, Unger, Genera et Spec. Plant. Foss. p. 424.

Bovey Tracey, in the 17th bed.

The two fragments figured are the only ones which were found; their apices are wanting, the determination therefore cannot be considered as quite sure. The leaf, however, agrees in its size, form, and nervation with *C. Rossmässleri*. Only a little piece is wanting in the leaf represented in fig. 18, as the raised sides show; the two lateral nerves run, however, to the end of the preserved part, and are so distinct there that undoubtedly they reached to the apex, which forms the principal character of the leaf, which is nearly related to *C. zeylanicum*, Bl., and still more to *C. eucalyptoides*, Nees (*C. nitidum*, Hook.). The leaf has a tolerably slender petiole; it is broadest in the middle, and equally tapered towards both ends. The two lateral nerves springing above the base are pretty strong, and run parallel with the margin. The very delicate nervules spring at right or at least not very acute angles.

19. Cinnamomum Scheuchzeri. (Plates LXVII. figs. 9–16; LV. fig. 4 *e*; LXVIII. fig. 12.)

C. foliis petiolatis, ellipticis, ovalibus et oblongis, triplinerviis, nervis lateralibus margine parallelis vel subparallelis, apicem non attingentibus; pedunculis articulatis, pedicellis apice incrassatis, fructibus ovatis.

Flora Tertiaria Helvetiæ, ii. p. 85, pl. 91. figs. 4–24, pl. 92, pl. 93. figs. 1–5.

Rather frequent in the 17th and 26th beds at Bovey.

These are leathery, entire, and three-nerved leaves, which are broadest in the middle, and gradually and equally tapered towards both ends; they are acuminated at the base in the same manner as at the apex, without running into the petiole; the sides form almost regularly curved lines. The two strong lateral nerves are jointed above the base of the leaf; they are mostly opposite (Plate LXVII. figs. 11, 13 & 16), the one seldom a little higher than the other (Plate LXVII. figs. 10 & 15); they run parallel with the margin. They do not reach to the apex of the leaf, but they unite above the middle of the leaf with a secondary nerve of the midrib (figs. 10 & 11). The areas are provided with very delicate nervules, which spring at almost right angles. I found the two flowers which are represented in Plate LXVIII. figs. 13 & 13 *c* (magnified 13 *b* and 13 *d*) in the 26th bed of Bovey. They very much resemble the flower from Oeningen represented in the 'Flora Tertiaria Helvetiæ,' pl. 91. fig. 23 *b*, and therefore probably belong to *Cinnamomum Scheuchzeri*. The leaflets of the perianthium of the flower represented in fig. 13 *c* are indistinct; they are much better preserved in fig. 13 (magnified 13 *b*). There are six leaflets, standing in two whorls around a circular wall. The leaflets are hard, shortly oval, obtusely rounded at the apex, and provided with longitudinal striæ. They are shorter and broader, and more obtusely rounded than in *Cinnamomum polymorphum*, A. Br. (cf. Flora Tertiaria Helvetiæ, pl. 94. figs. 1–5). We have beautiful branches from Oeningen with leaves of this species. We lately got a branch with the inflorescence, which confirms the systematic position which I assigned to the leaves. I therefore represent this branch in Plate LXVII. fig. 12. Numerous flowers, still in the state of buds, but nearly breaking off, are lying together, and sometimes one above the other, so that it is not possible to find out their insertion with certainty. One sees, however, that the peduncles spring from the axils of the leaves, and we have therefore an axillary inflorescence. The peduncles are club-shaped above, and this part forms with the bud an almost globose body, on which the leaflets of the perianthium are indicated at some places. These peduncles lengthen afterwards and become more sharply articulated, as the peduncles and fruit-stalks which I have represented in my 'Flora Tertiaria' (pl. 91. figs. 4–7) show.

It is very like *C. pedunculatum*, Thb., from Japan.

20. Cinnamomum lanceolatum. (Plates LXVII. figs. 1–8; LXVIII. figs. 14 & 15.)

C. foliis petiolatis, lanceolatis, basi apiceque acuminatis, triplinerviis, nervis lateralibus margine parallelis, approximatis, acrodromis, apicem non attingentibus.

Flora Tertiaria Helvetiæ, ii. p. 86, pl. 93. figs. 6–11.

Daphnogene lanceolata, Unger, Fossile Flora von Sotzka, p. 37.

Rather common in the 17th and 26th beds; it is also a leaf of the 54th bed.

Is like *C. Scheuchzeri*, but differs from it in the leaves being narrower, longer, elongated into a long point, and tapering towards the petiole.

The leaf is also leathery, strongly tapered towards the base, and gradually towards the apex, forming a long sharp point. The two strong lateral nerves are near the margin and run parallel with it; delicate secondary nerves proceed from the median nerve above the middle of the leaf and join them; several delicate secondary nerves follow more outwards. The areas are traversed with very fine nervules, and the secondary areas which these form are filled up with a fine polygonal reticulation. The nervules spring at almost right angles, and the upper secondary nerves at acute angles. Fig. 1 represents a leaf of the 26th bed, the others are of the 17th; figs. 5 & 6 represent young leaves.

3. Daphnogene, Ung.

21. Daphnogene Ungeri, Hr. (Plate LXV. figs. 1 & 2.)

D. foliis lanceolatis, basi subrotundatis, longe petiolatis, triplinerviis, nervis basilaribus margine subparallelis, nervulis obsoletis.

Flora Tertiaria Helvetiæ, ii. p. 92, pl. 96. figs. 9–13.

Ceanothus lanceolatus, Ung., Fossile Flora von Sotzka, p. 49.

Bovey, in the 26th bed.

This leaf differs from those of *Cinnamomum Scheuchzeri* and *C. lanceolatum* in being widest below the middle, and in the delicate nervules being absent in the large areas. In most of the leaves of this species from our molasse, and also from Manosque in Provence, the base of the leaf is rounded, which is not the case in the Bovey leaves; but since also at Sotzka (cf. Unger, plate 31. fig. 14) leaves occur of which the base is not so much rounded off, we may without hesitation unite the Bovey leaves with the above-mentioned species. The leaf (fig. 2) otherwise agrees very well with that which is represented by Unger.

The leaves are hard, coriaceous; they attain the greatest breadth below the middle, and taper gradually to the apex. The strong lateral nerves run near the margin and parallel with it; they have no visible nervules in the areas.

Fam. II. Proteaceæ, R. Br.

4. Dryandroides, Ung.

22. Dryandroides hakeæfolia, Ung. (Plate LXV. fig. 12 *a*.)

Dr. foliis coriaceis, firmis, lanceolatis lineari-lanceolatisque, in petiolum attenuatis, apice acuminatis, plerumque apice dentatis, dentibus remotis, inæqualibus, nervo medio valido, nervis secundariis subtilissimis, camptodromis, areis marginem fere attingentibus, nervatura firma, hypodroma, areolis magnis scrobiculatis.

Unger, Fossile Flora von Sotzka, p. 39, pl. 20. figs. 7–10.
Heer, Flora Tertiaria Helvetiæ, ii. p. 100, pl. 98. figs. 1–13, plate 99. figs. 4–8.

Only fragmentary leaves have been found at Bovey (in the 17th bed), but they cannot be mistaken, since they have the characteristic nervation of this species. In one piece (which in fig. 12 *a* lies upon the slab with the apex pointing downwards) part of the margin is still complete, and shows the sharply indented teeth which *Dr. hakeæfolia* commonly has. In the same leaf the nervation is pretty well preserved. The secondary nerves are very delicate, and project but very little beyond the other reticulation. To the naked eye, or when but slightly magnified, the leaf appears dotted, owing to the distinctly projecting small arches which form the reticulation.

23. Dryandroides lævigata. (Plate LXV. figs. 9, 10 & 11.)

Dr. foliis coriaceis, firmis, lanceolatis, basi in petiolum attenuatis, apice attenuatis plerumque integerrimis, nervo medio valido, nervis secundariis manifestis camptodromis.

Flora Tertiaria Helvetiæ, p. 101, pl. 99. figs. 5–8.
In the 17th bed of Bovey.

It is very like the preceding species; but the margin is generally entire, and the nervation is more delicate, being less prominent.

The leaf of Bovey which has been represented in fig. 10 is coriaceous, lanceolate, and tapering gradually towards the tip, where it ends in a point; it is entire; the median nerve is rather strong, but the secondary nerves are very delicate; they reach to near the margin, where they form arches. The more delicate reticulation, which is formed by very small and densely crowded areoles, can be made out by the aid of a lens, but it is much less distinct than in the foregoing species.

The leaf agrees well with that which has been represented in plate 99. fig. 7 of my 'Flora Tertiaria.'

24. Dryandroides Banksiæfolia. (Plate LXVIII. fig. 7.)

Dr. foliis petiolatis, firmis, linearibus vel lanceolato-linearibus, undique argute serratis, basi apiceque acuminatis, nervis secundariis approximatis, subrectis, simplicibus, parallelis.

Flora Tertiaria Helvetiæ, ii. p. 102.
Myrica Banksiæfolia, Ung., Gen. et Spec. Pl. Fossil. p. 395.
Bovey, in the 26th bed.

Only the portion of a leaf represented in Plate LXVIII. fig. 7 has been found at Bovey. It cannot be determined with certainty, as the characters which the above diagnosis (copied from my 'Flora') contains are not recognizable in them.

It was certainly a hard leathery leaf with a very delicate nervation. The secondary nerves are but slightly indicated and run towards the teeth, which are very sharply cut. The fragment probably represents part of the leaf near the base, like plate 100. fig. 10

of the 'Flora Tertiaria Helvetiæ'; and that is the reason why the teeth are there wanting. We find them, however, in most of the leaves of *D. Banksiæfolia*.

Fam. III. SANTALACEÆ, R. Br.

5. NYSSA, Linn.

25. NYSSA EUROPÆA, Ung. (Plate LXIX. figs. 11–17.)

N. putamine 4½–7 mm. longo, 3–6½ mm. lato, ovali, rarius subgloboso, basi truncato, extus striis longitudinalibus rugosis exarato.

Unger, Sylloge Plantar. Fossil. p. 16, pl. 7. figs. 25–27.

Frequent in the 26th bed of Bovey.

The fruit most probably agrees with the fragments which UNGER described as found at Nidda in the Wetterau, and which I got from Salzhausen; the latter are, however, somewhat more compressed, and consequently more flattened; hence the wrinkled longitudinal ribs do not project so much. Very similar also is a fruit represented as *Nyssa rugosa* by O. WEBER in the 'Palæontographia,' ii. plate 20. fig. 10 *c*; this fruit differs, however, in its shape and smaller dimensions, from two other fruits that were mentioned by WEBER under the same name.

We distinguish amongst the Bovey fruits three forms:—

a. Oval fruits, 4½ to 5½ millims. long and 3 to 4 millims. wide; they are truncated at the base, in the fore part obtusely rounded and marked with numerous rather deeply wrinkled longitudinal furrows (figs. 11–14, magnified 12 *b*).

b. Oval fruits, 6–7 millims. long and 4–5 millims. wide; they are also truncated at the base, but somewhat rounded, marked with numerous wrinkled longitudinal furrows. They are shaped like the stones of *Nyssa sylvatica*, but are somewhat smaller (figs. 15 & 16).

c. Nearly globose fruits, 7 millims. long and 6 to 6½ millims. wide; at the base abruptly truncate, with strongly marked irregular wrinkled furrows (fig. 17, magnified 17 *b*).

The form *a* is the most frequent; the form *c* has been met with in but a few pieces; the form *b* is not rare, and corresponds most to the fruit-stones of the Wetterau. Whether these forms belong to one or more species, I dare not decide.

They are very like the fruit-stones of the species of *Nyssa* which grow at present in the United States, especially of *Nyssa biflora* and *denticulata*, which are represented by GÄRTNER (De Fructibus, iii. p. 216).

26. NYSSA LÆVIGATA, m. (Plate LXIX. fig. 18, magnified 18 *b*).

N. putamine 5–7 mm. longo, 4–5 mm. lato, ovali, basi truncato, lævigato, extus bistriato.

In the same bed of Bovey; rare.

It has the same dimensions and shape as the foregoing species, but it is smooth, shining, and without wrinkled furrows, notwithstanding we observe on the outside two longitudinal lines, which are formed, as in the fruit-stones of *Nyssa*, by delicate striæ.

27. Nyssa microsperma, m. (Plate LXIX. fig. 24, magnified 24 *b*.)

N. putamine 4 mm. longo, globoso, extus striis longitudinalibus rugosis exarato.

Only a single specimen from the same bed.

It is upon the whole very like the small forms of *Nyssa europæa*, but it is still smaller, perfectly globose, truncated at the base and deeply furrowed.

At the base of the fruit-stone appears a small hole; the sides are marked with deep longitudinal furrows, and the intervening ribs are wrinkled.

28. *Nyssa striolata*, m. (Plate LXIX. figs. 20–23, magnified 20 *b*.)

N. putamine 10–12 mm. longo, 6–8 mm. lato, compresso, ovali, tenuiter longitudinaliter striato.

Several specimens from the 26th bed.

It is very like the *Nyssa ornithobroma*, Ung. It is of the same shape and the same dimensions as the specimen represented by Unger (fig. 16), from which we must separate it, because the striæ are more delicate and more densely arranged. The small nuts are perfectly flattened, and at the base obtusely rounded, but they terminate in the apex in a small point. Along the middle of each specimen runs a longitudinal fissure, which was probably caused by pressure. The side is furrowed by numerous very delicate longitudinal striæ, while the intervening spaces are smooth.

Coh. II. *GAMOPETALÆ.*

Order I. BICORNES, Endl.

Fam. I. Ericaceæ, Dec.

1. Andromeda, Linn.

29. Andromeda vaccinifolia, Ung. (Plate LXVIII. fig. 9.)

A. foliis coriaceis, oblongis, integerrimis, apice obtusis, basi rotundatis vel subrotundatis, petiolatis.

Unger, Fossile Flora von Sotzka, p. 43, pl. 23. figs. 10–12.

Heer, Flora Tertiaria Helvetiæ, iii. p. 7, pl. 101. fig. 25.

In the 17th and 26th beds of Bovey.

I found several pieces, but only the one represented in fig. 6 has remained entire, the others have been ruined on the journey. This leaf certainly agrees with the leaves represented in my 'Flora,' figs. 25 *b* and 25 *c*. The leaf has a petiole and a pretty strong median nerve; the lateral nerves are obsolete, and the reticulation is not preserved.

30. Andromeda reticulata, Ett. (Plate LXVIII. figs. 10 & 11.)

A. foliis coriaceis, lineari-lanceolatis, acuminatis, basi in petiolum attenuatis, integerrimis, nervatione dictyodroma.

Ettingshausen, Tertiäre Flora von Haering, p. 65, pl. 22. figs. 9 & 10.

Bovey; several pieces in the 26th bed.

The leaf is hard, leathery, and tapers towards the petiole, narrow-lanceolate, the sides almost parallel; the apex is not preserved in the leaves of Bovey. The median nerve is pretty strong; the whole leaf is covered with a fine polygonal reticulation (fig. 10 *b*, a portion of a leaf magnified), which reaches from the median nerve to the margin and has almost everywhere meshes of the same size. Only at some few places in this reticulation there appear delicate secondary nerves, which rise at a very acute angle. It very well agrees in the form and nervation with pl. 22. fig. 9 of Ettingshausen's work.

This species is nearly related to *Andromeda protogæa*, Ung., and is perhaps a variety of it; the reticulation is, however, much more delicate, and can only be seen with the lens. The leaf of *Eucalyptus oceanica*, Ung., is similarly shaped, but the nervation is different.

Fam. II. Vaccinieæ, Dec.

2. Vaccinium, Linn.

31. Vaccinium acheronticum, Ung. (Plate LXVIII. fig. 8.)

V. foliis subcoriaceis, ovalibus vel oblongis, integerrimis, petiolatis.

Unger, Flora von Sotzka, p. 43 (ex parte), pl. 24. figs. 1, 3, 4 & 6.

Heer, Flora Tertiaria Helvetiæ, iii. p. 10, pl. 101. fig. 29.

Bovey, in the 26th bed.

A small longitudinal, oval and entire leaflet with a short petiole. The median nerve is thin, and several delicate curved secondary nerves proceed from it.

This leaflet is longer and more tapered at the base than those of the 'Flora Tertiaria Helvetiæ,' but it certainly agrees with the leaf represented by Unger in the 'Flora of Sotzka,' pl. 26. fig. 6, and may therefore be referred to this species.

Order II. CONTORTÆ, Endl.

Fam. I. Apocyneæ, R. Br.

1. Echitonium, Ung.

32. Echitonium cuspidatum, Hr. (Plate LXIV. figs. 3 *b* & 5; Plate LXV. fig. 12 *c*.)

E. foliis lineari-lanceolatis, apice cuspidatis, integerrimis, nervis secundariis numerosis, camptodromis, areis margini approximatis, reticulatis.

Heer, Flora Tertiaria Helvetiæ, iii. p. 192, pl. 154, figs. 4–6.

Several pieces of leaves from the 17th bed of Bovey.

The more delicate nervation is almost obliterated in the fragments of the leaves from Bovey, but these agree well with our species as to their forms and the direction of the secondary nerves; nevertheless this determination cannot be considered to be quite certain. Very similar is a leaf from the lignite of the Rhine, which is represented by O. Weber as *Labatia salicites* (Palæontogr. iv. p. 154, pl. 28. fig. 1); but the leaves of Bovey, like those of Locle, taper into a more elongated apex, and the arches of the secondary nerves approach nearer the margin.

The leaf is very long and narrow, tapering gradually towards the base; and also elongating into a very long point. From the median nerve spring rather numerous secondary nerves, which are highly incurved, forming near the margin arches that run nearly parallel with the latter; these arches are very delicate, and can only be traced by the aid of a lens. The reticulation of the areas is only slightly indicated.

Order III. RUBIACINÆ.

Fam. I. Rubiaceæ, Juss.

1. Gardenia, Ell.

33. Gardenia Wetzleri, Hr. (Plate LXIX. figs. 1–8.)

G. fructibus lignosis, oblongo-ovalibus vel ovato-lanceolatis, subcostatis et multistriatis, polyspermis, seminibus nigro-brunneis, nitidis, striis spiralibus notatis.

Heer, Flora Tertiaria Helvetiæ, iii. p. 192, pl. 141. figs. 81–103.

Passiflora Braunii, Ludwig, Palæontograph. viii. p. 124, pl. 48. figs. 1, 4, 5 & 16.

Bovey Tracey, in the 34th bed.

At Bovey no complete fruits have been found like those which we know from near Königsberg, from the brown-coal of the Rhön and Wetterau and of Günzburg, but we have got rather numerous seeds, partly still in the position which they held within the fruits (cf. Plate LXIX. figs. 1 & 2). These seeds agree, in respect to their position, their forms, and the peculiar structure of the testa, so entirely with those of the Continent, that no doubt can arise about the question whether they belong to the same plant or not. They are arranged in series, but in such a manner that they partly overlie each other; and in consequence of pressure the shape has been here and there somewhat altered, resulting in more or less deep impressions. Figures 3–5 (magnified) show the principal forms which the seeds of Bovey display. At the apex they taper into a small point, at the base they are somewhat rounded; the colour is a shining brownish black, furrowed by very delicate striæ forming distinct spirals, the deeper striæ alternating with the more delicate (cf. especially the highly magnified piece of a seed, fig. 6).

In order to illustrate this remarkable species, which has such a very wide range, I have represented in fig. 7 a fine fruit that was sent me by Director Albrecht of Königsberg out of the clays of Samland; fig. 8 represents a similar fruit from Günzburg, remarkable for its great dimensions.

In the 'Flora' (*l. c.*) I have described this species at full length, and I have tried to show that it belongs to the genus *Gardenia*, while Ludwig refers it to *Passiflora*. It cannot belong to the latter genus, since *Passiflora* has fleshy fruits on long slender stalks, and seeds which are always distinguished by peculiar little pits ("semina impresso-scrobiculata" is mentioned by Endlicher as a characteristic feature of this family). Even the genus *Vareca*, to which Ludwig refers, has fleshy hexagonal fruits, which are only about half an inch long, and furnished at the base with a small round cup with six

notches; of the seeds each rests in a separate cell: all these are peculiarities which are not met with in the fossil fruit (cf. Gärtner, De Fructib. et Seminib. i. p. 290).

In the 'Flora' I have enlarged upon the reasons why I united these fruits and seeds with *Gardenia*. The *Gardenia lutea*, Fres. and *G. Thunbergii*, L. fil., have also ligneous fruits with a pericarp furrowed by similar longitudinal fibres, and they are also supported on short and thick stalks that pass gradually into the fruit; besides we remark, exactly in the same manner as in the fossil fruit of Königsberg, represented in fig. 7 *b*, the placentæ parietales forming ridges, which project from the inner surface, and which constituted most probably soft membranaceous partitions proceeding towards the interior. The seeds of some Gardenias are arranged in series of which the number varies—in one fruit, known from the Brazils, in four, in others in more series; the number of the placentæ also varies from two to six. Thus we have in *G. Thunbergii* five, in *G. lutea* six, while the seeds lie together in great numbers and are indistinctly arranged in series; they are horizontal; in the fossil fruit they are also horizontal, but generally somewhat obliquely turned towards the bottom, with the point directed towards the base of the fruit. They are arranged in series, which are, however, but very seldom as distinctly marked as is the case in the pieces represented by Ludwig. I thought I could distinguish five series, but Ludwig mentioned six; and if so, we should in these fruits assume three placentæ, to each of which two series of seeds are fixed. Yet in the fruit from Königsberg there seem to exist four placentæ; two are visible in the interior of the one-half of the fruit of which the outside is represented in fig. 7 *b*, and two seem to be on the other half (7 *a*); one, which is very distinct, runs somewhat beyond the middle throughout the fruit, and another seems to have existed on the right side at the edge; this latter, however, is indistinct and uncertain. In fig. 7 *c* I have represented the transverse section; the line marks the place where the fruit was broken into halves: also from Salzhausen I got only fruits which were thus split in the middle into halves. I do not know upon what grounds M. Ludwig supposed that the fruit was divided into three valves. It was certainly an indehiscent fruit.

Coh. III. *POLYPETALÆ*.

Order I. UMBELLIFLORÆ.

Fam. Ampelideæ, Kunth.

1. Vitis, Linn.

34. Vitis Hookeri. (Plate LXIX. figs. 27, 28 & 29.)

V. seminibus parvis, 3½ mm. longis, 3 mm. latis, brevibus, ovato-acuminatis, læviusculis, dorso convexiusculis, tuberculo chalazino rotundato magno.

Bovey Tracey, in the clay of the 26th bed.

I have got but one single seed of this species, which, however, cannot be mistaken. It is very like those of the grape of Salzhausen, which A. Braun described as *Vitis*

teutonica, and of which UNGER (Syllog. Plantarum, p. 23, pl. 9. figs. 1–8) and LUDWIG (Palæontogr. viii. p. 118, pl. 45. figs. 1–5, pl. 46. fig. 6) lately gave descriptions and drawings; it is a species which had a very wide range, and which I pointed out as occurring at Oeningen, in the brown coals of the Rhön and at Schossnitz. The seed of the grape of Bovey is, however, smoother, comparatively wider and shorter; more flattened on the dorsal part, and the little pits on the ventral surface are less deep; while also the small wart (verruca) on the back is somewhat larger, for which reasons we must separate the seed of this grape as a different species.

It is most obtusely rounded at the base, and terminates at the apex in a little short point; upon the dorsal part (fig. 29, six times magnified fig. 29 *d*) it is only slightly convex; the chalazal tubercle (tuberculum chalazinum) is large and nearly circular; upon the ventral part (fig. 29 *b*, *c*) appears a rather prominent ridge, along the middle of which runs, as in *Vitis teutonica*, a delicate longitudinal stria; on each side of the ridge we observe a small pit (scrobicula), which, however, is much less deep than in *Vitis teutonica*.

To this or the following species belong probably the grapes from the 17th bed of Bovey (figs. 27 & 28), which are very like those of *Vitis teutonica*. They are flattened, nearly circular fruits, in the interior of which no grains can be distinguished, as in those from the brown coals of Langenaubach (cf. LUDWIG, *l. c.* p. 120).

Fig. 29 represents the dorsal surface of the seed; fig. 29 *b*, the ventral surface; fig. 29 *c*, *d*, magnified; fig. 29 *c*, section; figs. 27 & 28, grape.

35. *Vitis britannica*, m. (Plate LXIX. figs. 25 & 26.)

V. seminibus parvulis, 5½ mm. longis, 3 mm. latis, ovato-ellipticis, dorso planis, tuberculo chalazino obsoleto.

From the 26th bed of Bovey.

Of this species I got two seeds, which belong probably to *Vitis* or *Cissus*; but the chalazal tubercle is not distinct, and the consequent determination cannot be considered to be quite certain. These seeds are longer and comparatively narrower than those of the foregoing species; on the ventral side we observe the prominent ridge; the pits on both sides are very flat and oblong; the dorsal part is flattened. On one seed (the other is much compressed) we observe an oval tuberculum chalazinum, which appears, however, flat, imperfectly stamped out, and therefore indistinct.

Order II. POLYCARPICÆ, Endl.

Fam. ANONACEÆ, Dun.

1. ANONA, Linn.

36. ANONA (?) DEVONICA, m. (Plate LXX. figs. 1–3.)

A. seminibus ovalibus, 19–21 mm. longis, 12–14¼ mm. latis, compressis, lævisculis.

A good many specimens from the 26th bed of Bovey.

Belongs probably to *Anona altenburgensis*, Ung. (Sylloge Plantar. p. 26, pl. 10. figs. 8–11). The representation agrees pretty well with the seeds of Bovey; but as Unger in the diagnosis calls the seeds "ovato-oblongis," and since those of Bovey are no wider at the base than at the top, I dare not to unite them with those of Altenburg.

Most of the specimens are 20 to 21 millims. long, widest in the middle, narrowing symmetrically towards both ends, where they are most obtusely rounded. They are flat, the diameter only amounting to $2\frac{1}{2}$ millims.; throughout they are formed of an homogeneous mass of coal, which has obliterated all traces of the contents of the seeds. On the outside they are smooth and rather shining when rubbed; sometimes they appear reticulated by delicate fissures, or furrowed with very fine longitudinal and transverse striæ, which are, however, much obliterated, and can only be perceived by the aid of a lens. In some pieces the middle portion is perfectly flat and slopes towards a rather sharp margin (cf. section, fig. 2 *b*), thus forming a flatly bordered seed like those of *A. paludosa*, Ait.; in others the margin is blunted. In one piece (fig. 3) the middle portion has fallen out, thus producing a broad and deep furrow; this is probably only accidental.

In fig. 1 the seed still lies within the stone, convincing us that it is not surrounded by a shell. The perfectly homogeneous substance of the coal indicates a seed and not a fruit; and since the Anonas (especially the *A. paludosa* and *Asimina triloba*) have quite similar seeds, I agree with the determination of Unger, although it cannot be denied that it must be considered as somewhat doubtful till other organs shall be discovered.

37. Anona cyclosperma, m. (Plate LXX. fig. 4.)

A. seminibus suborbiculatis, 14 mm. longis, 11–12 mm. latis, compressis, rugulosis.

At the same spot; several specimens.

They are very like the preceding, but much smaller, especially much shorter; and as the breadth is nearly the same, they are almost orbicular; a network is constituted by numerous irregular fissures, which cause the outside to be somewhat wrinkled (fig. 4 *b*). Since no intermediate forms occur between this and the foregoing, they seem to belong to different species.

Order III. HYDROPELTIDEÆ.

Fam. Nymphæaceæ, Salisb.

1. Nymphæa, Linn.

38. Nymphæa Doris, m. (Plate LXX. figs. 32–37.)

N. seminibus ovalibus, $2\frac{1}{2}$–$3\frac{1}{2}$ mm. longis, subtilissime crenulato-striolatis, apice poro perforatis.

From the 64th bed.

Tolerably numerous flattened seeds lying close together: they are oval, $2\frac{1}{2}$ to $3\frac{1}{2}$ millims.

long and 2 to 3 millims. wide; at both ends they are obtusely rounded, and at one end are furnished with a small round hole (fig. 33, magnified fig. 34; fig. 35, magnified fig. 36), which is only visible in those specimens that are compressed from above. The sides are furrowed by very delicate and elegant longitudinal striæ, formed by the cells, which are arranged in lines. They are neatly crenated and very delicately dotted (cf. fig. 37, a highly magnified piece, of which only part of the testa has been preserved). This elegant sculpture can only be made out by the aid of a lens or microscope.

They are very much like the seeds of *Nymphæa alba*, especially the form with the larger seeds, the *Nymphæa alba melocarpa*, Casp. In the recent seeds the longitudinal striæ appear much less distinct; but in such seeds as are found in the 'Pfahlbauten' of Robenhausen, they look exactly like those of the fossil species. In these also the hole on the top of the seed is somewhat more widened, as in the fossil species. As to the shape, the latter differs in so far as the seeds are comparatively somewhat wider (those of *N. alba melocarpa* are $3\frac{1}{2}$ millims. long and 2 millims. wide): this more considerable breadth may have been caused by pressure, since they are all highly compressed. To the same circumstance we may ascribe the fact that the raphe cannot be pointed out distinctly.

The seeds of Bovey are very like those of my *Nymphæa Charpentieri* (Flora Tertiaria, iii. p. 195, pl. 155. fig. 20 *b*, *c*), the latter being only somewhat narrower. It would therefore be very desirable that the leaves be sought for at Bovey, since from these alone can it be decided with certainty whether this species is really distinct from *N. Charpentieri*, to which it comes very near. The seeds of the living *Nymphææ* are variable in their dimensions.

Order IV. MYRTIFLORÆ.

Fam. Myrtaceæ, R. Br.

1. Eucalyptus, Hérit.

39. Eucalyptus oceanica, Ung.? (Plate LXIX. figs. 9 & 10.)

E. foliis coriaceis, 2–5-pollicaribus, lanceolatis vel lineari-lanceolatis, acuminatis, subfalcatis, in petiolum attenuatis, integerrimis, petiolis semipollicaribus, sæpius contortis, nervo primario distincto, secundariis subtilissimis.

Unger, Flora von Sotzka, p. 58, pl. 36. figs. 1–13.

Heer, Flora Tertiaria Helvetiæ, iii. p. 34, pl. 108. fig 21, pl. 154. figs. 14 & 15.

In the clay of the 26th bed.

As at Bovey only fragments of leaves have been found, no sure determination can be given. The leaves are smooth, shining, coriaceous, somewhat incurved, and taper towards the tip. The secondary nerves are very delicate and form arches, which run nearly parallel with the margin. Close by the leaf (represented in fig. 9) lies the top of a leaf of a quite different plant, which seems to belong to *Quercus Lyelli*.

2. Eugenia, Mich.

40. Eugenia Hæringiana, Ung. (Plate LXVIII. figs. 16, 17 & 18.)

E. foliis coriaceis, lanceolato-linearibus, in petiolum brevem crassumque attenuatis, integerrimis, nervis secundariis distantibus, simplicissimis, camptodromis, duobus inferioribus valde elongatis.

Unger, Flora von Sotzka, p. 52, pl. 35. fig. 19.

Heer, Flora Tertiaria Helvetiæ, p. 34, pl. 2. fig. 1, pl. 108. fig. 16, pl. 154. fig. 13.

Bovey, in the 26th bed.

The leaves of Bovey are very like the leaf of Ralligen represented in my 'Flora,' pl. 108. fig. 16. They are leathery, entire, long and narrow, and tapered towards the petiole, the sides being almost parallel. The two long secondary nerves are very near the margin, and run nearly parallel with it. We cannot distinguish the finer nervation.

Resembles *Cinnamomum lanceolatum*, but the leaf is longer, relatively narrower, and has parallel sides.

Order V. FRANGULACEÆ.

Fam. Celastrineæ, R. Br.

1. Celastrus, Linn.

41. Celastrus pseudo-ilex, Ett. (Plate LXVIII. fig. 19.)

C. foliis coriaceis, lanceolato-linearibus, sessilibus, integerrimis, nervo medio debili, secundariis camptodromis.

Ettingshausen, Tertiäre Flora von Haering, p. 70, pl. 24. figs. 30–36.

Heer, Flora Tertiaria Helvetiæ, p. 69, pl. 121. fig. 57.

I found several leaflets in the 26th bed of Bovey; unhappily most of them have been ruined in the journey, and only the piece represented in fig. 19 *b* has remained entire. I drew the piece represented in fig. 19 (magnified 19 *b*) on the spot. These are small, stiff, entire and narrow leaflets, obtusely rounded at the apex. Short lateral nerves proceed from the delicate median nerve. It certainly agrees with the leaves of Haering, and those of Locle and Oeningen.

It may be compared to *Celastrus integrifolius*, Thunb., from the Cape.

Order VI. TEREBINTHINEÆ.

Fam. Juglandeæ, DeC.

Pterocarya, Kunth.

42. Pterocarya denticulata? (Plate LXX. fig. 5.)

Pt. foliis pinnatis, foliolis sessilibus, lanceolatis, acuminatis, argute et creberrime serratis, nervis secundariis numerosis.

Heer, Flora Tertiaria Helvetiæ, iii. p. 94, pl. 131. figs. 5–7.

Juglans denticulata, O. Weber, Palæont. p. 211.

Bovey, in the 26th bed.

This species remains still very doubtful, since nothing but the fragments of leaves represented was found at Bovey. The diagnosis has therefore not been made from these fragments, but from the very fine leaves that were found in our molasse; further discoveries alone can prove whether the fragments of leaves found at Bovey belong really to this species.

The leaf of Bovey is very acutely toothed, and the teeth (augmented in fig. 5 *b*) are highly inclined towards the apex. The secondary nerves are delicate, and for the most part perfectly obliterated.

Order VII. LEGUMINOSÆ, Endl.

Fam. Papilionaceæ, Linn., R. Br.

Leguminosites, Bow., Heer.

43. Leguminosites areolatus, m. (Plate LXVIII. fig. 20, magnified fig. 20 *b*).

L. foliolis subcoriaceis, integerrimis, ovalibus, basi valde inæquilateris, nervis secundariis subtilissimis, camptodromis, areis argute reticulatis.

Bovey, in the 26th bed.

Is very like *Leguminosites sclerophyllus* (Flora Tert. Helvet. p. 123), but much more delicate, smaller, and with a sharper reticulation. It may belong to *Copaifera*.

A small leaflet, which has unequal sides at the base. The median nerve is curved and delicate. The secondary nerves are very delicate, at a great distance from each other, and jointed in large arches. The areas are filled up with a very delicate, distinctly projecting polygonal reticulation. The areoles are of equal size.

Incertæ Sedis.

Carpolithes, Sternb., Heer, Flora Tertiaria Helvetiæ, iii. p. 139.

44. Carpolithes Websteri. (Plate LXX. fig. 6, magnified 6 *b*.)

C. fructibus oblongis, subcompressis, utrinque obtusis, supra basim incurvatam paulo constrictis, longitudinaliter rugoso-striatis, rima longitudinali dehiscentibus, monospermis, membrana interna tenera, libera (testa seminis?).

Carpolithes thalictroides, var. *Websteri*, A. Brongniart, Recherches sur les Ossemens Fossiles, par Cuvier, ii. pl. 11. fig. 5; Mémoires du Muséum, p. 317, pl. 14. fig. 6.

Carpolithes Kaltennordheimensis, Flora Tertiaria Helvetiæ, iii. p. 141, pl. 21. fig. 14, pl. 141. figs. 68 & 69.

Folliculites Kaltennordheimensis, Zenker in Leonhard und Bronn's Jahrbuch, 1833, p. 177, pl. 4. figs. 1–7.

Carpolithes minutulus, Sternb. Versuch. i. 4. p. 41.

Folliculites minutulus, Bronn, Lethæa, p. 849, pl. 35. fig. 11.

J. D. Hooker, "On some small Seed-vessels from the Bovey Tracey Coal," Quart. Journ. Geol. Soc. Lond. for Nov. 1855, p. 566, pl. 17.

Unger, Sylloge Plant. Fossil. p. 17, pl. 7. figs. 10–23.

Hippophaë disperma, Ludwig in Palæontogr. viii. p. 112, pl. 43. figs. 14–18 & 20.

Not rare in the 54th bed; very rare in the rhizome-bed.

The fruits of Bovey agree so perfectly with those of Kaltennordheim, of Rochette, &c., that they must be referred to that species. Geologically they are of great importance, as they have such a wide range in the Miocene formation; it is hence the more to be regretted that their systematic position remains still very doubtful, and that it has even not yet been shown whether these small bodies, which can so easily be distinguished by their characteristic form and structure, are fruits or seeds. Most authors (Brongniart, Zenker, Bronn, and Hooker) consider them to be fruits, while Unger (Sylloge, p. 18) declared recently that they must be seeds, referring to the seeds of coniferous trees: as such I considered them formerly, when I described them (though granting the doubts concerning their character) as *Pinus rhabdosperma*. In all those specimens which I had then seen, the peculiar constricted volva was not distinct; but it is also wanting in all the seeds of conifers which I know, as is also the prominent edge and the sculpture. More probably they are comparable with the seeds of *Samyda*, which have such a volva, and which agree besides pretty well in respect to their form; but then we must bear in mind that the organs in question are ligneous, that they are dehiscent by a longitudinal fissure, and that such facts are much against an interpretation as seeds, though in favour of the hypothesis that they might have had the organization of a fruit.

Hooker supposed them to be cryptogamic fruits, although he was not able to point out an analogy amongst the cryptogamic plants. He maintains this view by stating that in the interior of the fruit a delicate sac is frequently found, which he considers to be a sporangium. This interpretation seems to me not quite correct; the sac seems to result from the testa of the seeds. The dotted and the spiral fibrous cells covering the interior of the cavity are much more in favour of a phanerogamic than of a cryptogamic plant; and in respect of the sac remaining in the interior of the cavity, we know exactly the same organization in cherry-stones which have lain for a long time in water or in wet places. I opened a good many cherry-stones from the 'Pfahlbauten' of Robenhausen; in all, without exception, the seed had disappeared (although the shell was left intact), and in its stead a delicate sac remained, which lay close to the interior surface of the stone, and which could easily be removed. A perfect dissolution of the kernel had taken place, and only the testa remained. The organic contents of the seed must hence have become dissolved, and escaped, in a remarkable manner, through both the testa and the putamen, that no traces of them were left in the cavity of the cherry-stone. Only the ligneous cells of the stone and the testa resisted and were preserved. In the same manner, without doubt, we must account for the existence of the sac of *Carpolithes Websteri*. Sometimes an inorganic substance has been deposited in

the place formerly occupied by the seed, and the interior of the cavity of the fruit is then partly filled with it.

Ludwig (*l. c.*) has united these fruits with *Hippophaë*, adopting, without necessity, a new specific name. These fruits do not, however, agree in the least with those of *Hippophaë*, and decidedly cannot be referred to that genus. He believes that great numbers of such fruits were arranged close together upon the boughs, which circumstance probably led him to refer them to *Hippophaë*. But it seems to me doubtful whether those little heaps of fruits which he represented were really fixed on the boughs that lie close by, or whether they lie only accidentally near the boughs. If they are fixed on the boughs, it will be proved that they are phanerogamic fruits and not seeds, while the interpretation as *Hippophaë* is not justified, considering the other contradictory marks.

The *C. Websteri* has been described so frequently and so carefully, that any more detailed description would be superfluous. I refer the reader especially to the very exact description of Hooker (*l. c.*). Investigation with the microscope showed me that the sac in the interior of the fruit is formed by cells with very thin walls and of different lengths (cf. fig. 6 *d*, *e*), as represented by Hooker in fig. 7, and that the pericarpium, on the contrary, is formed by ligneous cells, which partly show a very curious undulating circumscription, and are dotted (fig. 6). They are arranged in series*.

45. Carpolithes scutellatus, m. (Plate LXIX. fig. 30, magnified 30 *b*.)

C. fructibus complanatis, margine acutis, rotundatis, basi truncatis, dorso costulatis.

A few specimens in the 26th bed at Bovey.

It is a perfectly flat fruit (or seed?) with an acute margin (cf. the section of fig. *c*); at the base it is truncated, at the sides much rounded, obtusely rounded above, nearly in the middle somewhat emarginate. From the base originate a few delicate, partly ramified ribs, which reach somewhat above the middle.

It is rather like the fruits of *Panax*, but the middle partition is wanting.

Since I had only one well-preserved fragment at my disposal, I could not cut it open in order to see whether it had one or two furrows. Perhaps it may be a seed, and not a fruit.

46. Carpolithes Boveyanus, m. (Plate LXX. figs. 7–14.)

C. nucula 3–4½ mm. longa, ovata, apice mucronulata, dorso leviter sulcata, monosperma.

Frequent in the 26th bed at Bovey.

* The drawing M. A. Brongniart has given of this species is very imperfect. I did not myself recognise his drawing as belonging to this species; but Dr. Falconer convinced me that it was so. I compared, in the British Museum, the *Carpolithes thalictroides*, var. *Websteri*, Brongn., of the Isle of Wight with the fruit from Bovey and Kaltennordheim, and am assured that they form one species. But the *Carpolithes thalictroides*, Brongn., must be separated from *Carpolithes Websteri*, as the fruit of the former species is cylindrical and acuminated, whilst the fruit of *C. Websteri* is obtusely rounded. Unhappily the place where these specimens of the Isle of Wight were found is not mentioned in the British Museum. The stone is dark, and different from the White Clay of Alum Bay, where plants are lying. Perhaps they are from the Bembridge series. Latterly I have received many seeds of this species from the Hempstead beds of the Isle of Wight.

It occurs of two different dimensions; some are 3 millims. long and $2\frac{1}{2}$ millims. wide; others are 4–$4\frac{1}{2}$ millims. long and $3\frac{1}{2}$ millims. wide. They agree, however, with the exception of the dimensions, so perfectly, that they cannot be separated.

These fruits are short, oval, rounded at the base, and furnished with a small round hole (fig. 7); the portion around the latter is somewhat wrinkled; at the apex it is furnished with a short little point. The sides are rather flat, and over each side runs a flat longitudinal furrow (fig. 8, magnified 8 *b* & 12 *b*). As the seeds lie in the soft clay, they have hardly been much compressed; the longitudinal furrows have therefore probably not been caused by the circumstance that the pericarpium was pressed in along the cavity of the fruit, but probably are characteristic of the fruit. If we open the fruit in a longitudinal section (fig. 9, and magnified 9 *b* & 10, and of the smaller fruits 13 & 14), we perceive an elliptical partition, which contained, doubtless, one seed, of which, however, nothing is preserved. The wall of the pericarpium is relatively very thick; it must therefore have been ligneous. In a few of the smaller fruits there was a longitudinal fissure.

The whole organization shows that we have here fruits, and not seeds. It is very like the fruit of *Potamogeton* (cf. *Potamogeton Eseri*, Heer, Flor. Tertiar. Helvet. i. p. 102, pl. 47. fig. 8); but the shape of the cell of the fruit (loculamentum) differs and makes it doubtful whether it belongs to this genus. In *Potamogeton* the dorsal part of the fruit is generally much more convex than the ventral part, while the apex of the fruit is somewhat incurved.

47. Carpolithes nitens, m. (Plate LXX. figs. 15–23.)

C. fructibus subglobosis, nigro-nitidis, subtilissime et obsolete striolatis, monospermis, basi truncatis, cicatrice orbiculata vel angulata ornatis.

Taxus margaritifera, Ludwig, Palæontograph. viii. p. 73, pl. 60. fig. 19?

Very frequent in the coal of the 46th bed.

Ludwig gives only a short description, which agrees, however, pretty well, but for the expression "a circular plate with a thin margin and a short stalk*," which I do not understand, and the dimensions, since his fruits are 6 millims. long, whilst those of Bovey are only 5 millims. The seeds of *Taxus* display a similar organization of the cicatrix; it is always regularly orbicular or oval; and the delicate longitudinal stripes are also met with; but the walls are much thicker, and the internal cavity is much smaller. Nevertheless I do not know any genus with seeds and fruits which are so similar to those of Bovey as the seeds of *Taxus*. If it really belong to this genus, we should have a thick ligneous testa, and but a small cavity.

These little shining black bodies have nearly the same breadth and height (of 5 millims.), and are therefore nearly orbicular, although they are frequently compressed in different directions. On the fore part of the perfectly preserved specimens we observe a little point or apex; the base is truncate, and in the middle appears a small round hole,

* Dünnrandige und kurzgestielte Kreisfläche.

surrounded by a cicatrix of a dull colour, which is frequently orbicular, but sometimes polygonal. If we cut them open we observe a small cavity, surrounded by a ring of shining black brittle coal (figs. 19 *b*, 20, 21 & 22). Fig. 22 is a magnified transverse section of the middle; fig. 20 (magnified 20 *b*) a similar section, but nearer the top of the fruit, which is not compressed; and fig. 19 (magnified 19 *b*, 21) a section of a compressed fruit. The wall of the fruit measures 1 to 1½ millim.; the cavity has a diameter of about 2 millims. The black shining crust which covers the internal surface is very thin. It is formed by the testa, if the organization belong to a fruit; but if it be the seed of a *Taxus*, or of some tree resembling the latter, then it ought to be considered as the remains of the albumen, while the wall forms the ligneous testa. The cavity is always filled with a whitish-grey clay. As in the *Carpolithes Websteri*, the softer internal parts of the seed were also in this case dissolved, while the cavity became afterwards filled with mineral substance. The crust of coal corresponds to the cuticula of *C. Websteri*.

48. Carpolithes exaratus. (Plate LXX. fig. 27, highly magnified in figs. 24–26.)

C. putamine subgloboso, 3½ mm. longo, nigro, nitido, sulcis rugoso-punctatis exarato.

In the 26th bed at Bovey.

A remarkable little object, which represents, without doubt, the stone of a fruit. It is 3½ millims. long and $3\frac{3}{10}$ millims. wide, being thus nearly orbicular, although it is furnished with a rather blunt apex, which projects but very little, while the lower end is rounded very obtusely. At one place we observe a narrow fissure, which reaches from the apex to somewhat below the middle of the little stone, which is bordered by a narrow margin. It is, without doubt, the place where the raphe passed, and it may therefore be described as the umbilical fissure. The furrows and ribs upon the little stone are very elegant. On the truncated end (fig. 26, highly magnified) we observe a great many parallel furrows and ribs, which run very near one another to the lower termination of the umbilicus, and which pass also opposite the umbilicus across the back of the little stone; the sides too are marked by similar ribs and furrows; but here the first two are distant, and the furrows are therefore wider; the ribs run much more irregularly, forming ramifications, so that the furrows seem to be interrupted by numerous tubercles. The furrows and the ribs are covered besides with innumerable dots. (In fig. 24 *b*, a piece with a few ribs has been represented as seen under a microscope.)

Similar fruit-stones occur in *Celtis*, but we miss the umbilical fissure and the regularity of the furrows. As regards the character, the stone is more like those of *Prunus*, in which we observe on the suture a channel, within which the raphe runs till it passes through a hole below the apex of the stone towards the seeds. On the fossil we find no such small hole resembling a dot, but only the above-mentioned fissure; besides it differs in the very peculiar sculpture, and must therefore belong to another type of plants.

Fig. 27 represents the little stone of the natural size; fig. 24, the same magnified and viewed laterally; fig. 25, the same from the side of the umbilicus; fig. 26, from the base.

49. Carpolithes vinaceus, m. (Plate LXX. figs. 28 & 29, magnified 29, *b*).

C. semine gigantoideo, tenuissime longitudinaliter striolato, medio unisulcato.

Some pieces from the 26th bed.

This has the form and dimensions of the seeds of the grape (*Vitis vinifera*, Linn.), but it does not belong to the genus *Vitis*; the delicate longitudinal striæ, and the absence of the umbilicus within the fissure, are against such an hypothesis. It seems to me to be the seed of a monocotyledonous plant.

The seed is $6\frac{1}{2}$ millims. long, and at the thicker portion 4 millims. wide; at one end it is much thickened and obtusely truncated, towards the other it is much narrowed. It has a brown, rather shining testa, marked by very delicate striæ. In some places where the testa is removed (fig. 29, magnified fig. 29 *b*), the striæ (or rather the casts of the striæ) are more distinctly visible. They form very delicate longitudinal lines, which are here and there united by transverse lines.

50. Carpolithes lividus, m. (Plate LXX. figs. 30 & 31.)

C. follicularis, membranaceus, brunneus, ovatus.

In the 26th bed; several pieces.

A very doubtful species. Small light-brown oval bodies, with a thin membrane. One perfectly preserved specimen (fig. 30) is $4\frac{8}{10}$ millims. long and 4 millims. wide; it is quite flattened; on the dorsal part it is furrowed by transverse wrinkles (fig. 30 *b*), which were, however, produced by shrinking; otherwise it is smooth, shining, and of a yellowish brown; on the other side there is a longitudinal fissure (fig. 30 *c*, magnified), through which probably the seed fell out, leaving the thin membrane of the pericarp. In such a case it would be a small folliculus, with probably but one seed. It is also possible that it may be the testa of a seed, and that the fissure marks the raphe.

II. *Descriptions of the Diluvial Species of Plants.*

1. Salix, Linn.

1. Salix cinerea, Linn. (Plate LXXI. figs. 1 *a*, *b*, 2 & 3.)

S. foliis lanceolato-obovatis, basi angustatis, apice breviter acuminatis, serratis vel subtiliter undulato-serrulatis, rugulosis, nervis secundariis valde camptodromis nervillisque validis.

Several leaves lie upon the soft white clay, which cannot be distinguished from those of *Salix cinerea*, Linn.; they are like the leaves which occur in the tuffs of Cannstadt. The leaves represented on Plate LXXI. fig. 1 *a*, *b*, are distinctly serrated; the leaf *a* with a rather sharp point; the same is seen on the leaf fig. 3, while the larger leaf, which is represented in fig. 2, has only a slightly undulated and indistinctly denticulate margin, as occurs frequently in *Salix cinerea*. The secondary nerves are perfectly like those of *S. cinerea*; they are inclined forwards, and united, forming long arches, which approach the margin. The nervules are strong, and impart to the leaf a rather wrinkled aspect.

From the midrib spring shortened secondary nerves, which are united with each lower secondary nerve, a character peculiar to the leaves of the willows.

2. Salix, spec. (Plate LXXI. figs. 4 & 5.)

S. foliis petiolatis, oblongis, basi rotundatis, integerrimis (?), rugulosis, nervis secundariis valde camptodromis nervillisque validis.

This is doubtless the leaf of a willow, since it has the same characteristic nervation; the base of the leaf is obtusely rounded, and the margin seems to be entire. The specimen represented in fig. 4 has nearly parallel sides, but the base is obtusely rounded; on the margin no teeth are visible. The secondary nerves are also highly inclined towards the apex, and numerous nervules cause the wrinkled appearance of the surface. The small leaf which is represented at fig. 5 belongs undoubtedly to the same species with the foregoing, although the sides are less parallel. It is very like the leaves of *Salix amygdalina*, Linn., which vary very much in shape; but the secondary nerves and the nervules are strong, and the margin seems to be entire.

3. Salix repens, Linn.? (Plate LXXI. figs. 1 *c–h*, 6 & 7 *b*.)

S. foliis breviter petiolatis, ovalibus, oblongis et oblongo-lanceolatis, integerrimis, nervis secundariis valde curvatis.

The most frequent leaf of the white clays. Numerous fragments lie confused in all directions.

Some forms are rather similar to those of *Salix cinerea*, Linn., but the nerves are not nearly so strongly developed: the surface of the leaf is much smoother, and the margin is not dentate.

The dimensions and the form of these leaves are very variable. The length varies from 6 to 45 millims.: some are short, oval, and obtusely rounded at the apex; others (and they are the most numerous) are oblong, and rather obtuse at the apex; whilst others are lanceolate, and have an acuminate apex. There are so many intermediate forms, that these cannot be separated. The midrib is rather slender; from it rise the secondary nerves at a rather acute angle; they are highly curved towards the apex, and near the margin they are united in arches. The areas are divided by very delicate nervules. At some places the shortened secondary nerves, which pass over to the lower secondary nerves, are visible, but in most of the leaves this important mark is not quite distinct.

As to the shape and nervation of the leaves, it seems to me most nearly allied to *Salix repens*, Linn.; but the incurvate apex is wanting, which, however, does not always exist in *S. repens*. *Salix ambigua*, Ehrh., and *S. ambigua*, Sendtner (*S. aurito-myrtilloides*), have very similar leaves.

2. Betula, Linn.

4. Betula nana, Linn. (Plate LXXI. figs. 1 *k* & 7 *a*.)

B. foliis parvulis, orbiculatis, profunde crenatis, nervis secundariis flexuosis, craspedodromis, basalibus approximatis, areis nervulis reticulatis.

Very pretty little leaves, only 9 millims. long, and nearly orbicular. They have simple teeth, which are, however, deep and acute. From the median nerve arise on each side four secondary nerves, of which the two lowest are very much approximated. Each of them runs in a zigzag line, and terminates in a tooth; from the second spring tertiary nerves; and all are united, forming elegant polygonal reticulations, that can be traced upwards to within the teeth (cf. fig. 1 *k k*, where the leaf has been three times magnified). I saw several entire little leaves in an excellent state of preservation; there have been found besides several fragments of the leaves of this species in the white clay.

The nervation indicates the genus *Betula*. Similar forms occur in the young leaves of *Populus alba*; but in these, five primary nerves spring from the base of the leaf; while the nerves of *Betula* are pinnated, but the first ones approach the base, as seen in the fossil leaf; the reticulation also is that of *Betula*. A comparison of the different species of *Betula* leads us to *Betula nana*, Linn. The fossil leaves agree, indeed, in respect of dimensions, shape, dentation, and nervation so entirely with those of the living species, that no difference can be found; the petiole, however, is somewhat thicker than is generally the case with *Betula nana*.

Betula nana, Linn., is a boreal plant, which is at home throughout the whole arctic zone; it is found also here and there on the highland moors in Middle Europe, as, for instance, near Einsiedeln in Switzerland, and in the Jura. In the British islands it is found in Scotland only.

5. Pinus sylvestris, Linn.?

Dr. J. D. Hooker* speaks of a pine-cone which, according to the late Dr. Croker, was found in the upper layers of lignite. Dr. Hooker says that it so closely resembles that of a Scotch fir (*Pinus sylvestris*, Linn.), that it might be referred to this species. I have seen it in the collection of the Geological Society in London, and another specimen in Dr. Croker's collection at Bovey. I am of the same opinion as Dr. Hooker; but these cones look much more modern than the plants of the lignite beds, and they are, I believe, from the diluvial formation of Bovey.

III. *Insects from Bovey.*

During my stay at Bovey I carefully searched for the remains of insects. I found indeed some traces, but they are but fragmentary, and there is only one fragment which can be determined. It is the partly destroyed elytron of a beetle, probably a *Buprestites*, and which I shall describe as *Buprestites Falconeri* (Plate LXVIII. fig. 21, magnified 21 *b*). It was 8 millims. long and 3 millims. wide. The angle of the shoulder is somewhat rounded, and beneath it the elytron is somewhat curved inwards. It is remarkably sculptured; with the aid of a lens we can perceive numerous round points, which are ranged in rows, and so close together that the whole elytron gets quite a *sculptura alutacea*. The species of *Agrilus*, *Lampra*, and *Anthaxia* present a similar sculpturing.

* Quart. Journ. Geol. Soc., Nov. 1855, p. 566.

Explanation of the Plates.

PLATE LV.

Fig. 1. *Sphæria lignitum*, m.; fig. 2, magnified; fig. 3, more magnified. Fig. 4 *a*, *b*, *c*, *d*. *Pecopteris lignitum*, Gieb. Fig. 4 *e*. *Cinnamomum Scheuchzeri*, Hr. Figs. 5 & 6. *Pecopteris lignitum*. Figs. 7–10. *Palmacites Dæmonorops*, the fibrous bundles of the stem; figs. 11 & 12, spatha with spines; fig. 11 *b*, magnified; fig. 13, a spine; figs. 14 & 15, spines; fig. 15 *b*, magnified.

PLATE LVI.

Figs. 1–11. *Pecopteris lignitum*, Gieb.:—Fig. 1, the point of a leaflet (pinnula), magnified; figs. 2–4, parts of leaflets near the apex; fig. 5, many fragments of leaflets; fig. 5 *b*, seed, and *c*, the scales of a cone of *Sequoia Couttsiæ*; figs. 6 & 7, base of the leaflets; fig. 8, leaflet restored; figs. 9–11, young fronds. Figs. 12–15. *Lastræa Stiriaca*, Ung., sp.; fig. 12, fragment of a leaflet; fig. 13, leaflet with the sori, from Monod; fig. 14, pinnated leaf; fig. 15, leaflet.

PLATE LVII.

Figs. 1–7. *Pecopteris lignitum*, magnified. Fig. 8. *Lastræa Stiriaca*, magnified.

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PLATE LVIII.

Fig. 1. Rhizome of *Pecopteris lignitum*; fig. 2, rachis, with scars of the roots. Fig. 3. *Pecopteris Hookeri*, m.

PLATE LIX.

Sequoia Couttsiæ, m.:—Fig. 1, cone and seeds; fig. 2, cone, magnified; fig. 3, scales of the cone, magnified; fig. 4, scales of the cone; fig. 5, young shoots; figs. 6–8, young shoots, magnified; fig. 9, biennial branch; figs. 10 & 11, older branches; fig. 12, young shoot with the leaves, magnified; fig. 13, branch with three shoots in a verticil; figs. 14, 16 & 18, cones; figs. 15, 17 & 19, these cones restored.

PLATE LX.

Figs. 1–46. *Sequoia Couttsiæ*, m.:—Figs. 1 & 2, biennial branches; figs. 3–6, young shoots; fig. 6 *b*, magnified; fig. 7, base of a young shoot, magnified; fig. 8, young shoot, magnified; figs. 9, 11 & 12 *a*, young shoots with spreading leaves; figs. 11 *b* & 12 *a a*, magnified; fig. 10, young shoot with adnate leaves; figs. 12 *b b* & 13, part of a branch with short adhering leaves, magnified; figs. 14–20, young shoots; fig. 14 *b*, leaf, magnified; figs. 21, 23 & 24, scales of a cone; fig. 22,

base of cone; fig. 25, scale with the seeds; figs. 26–28, cones with separate scales; figs. 29–34, scales of cones; fig. 35 *a*, scales; fig. 35 *b*, seed; figs. 36–42, seeds; fig. 41 *b*, magnified. Fig. 43. *Amentum masculinum*; fig. 43 *b*, magnified; figs. 44 & 45, young shoots from Armissan; fig. 46, magnified. Figs. 47 & 48. *Sequoia sempervirens*; fig. 47, seed; fig. 47 *b*, magnified; fig. 48, cone. Fig. 49. *Glyptostrobus europæus*, Br., sp., from Hohe Rhonen; fig. 49 *b*, magnified. Fig. 50. *Palmacites Dæmonorops*, Ung., sp., fruit; figs. 51–53, magnified. Fig. 54. *Cyperites deperditus*, Hr.; fig. 54 *b*, magnified.

PLATE LXI.

Sequoia Couttsiæ, m., restored.

PLATE LXII.

Palmacites Dæmonorops, Ung., sp.:—Fig. 1, a large specimen, spatha?; fig. 2, three of the spines, magnified; fig. 3, a specimen with five spines; figs. 4–6, little spines; fig. 7, fasciculi of spines; fig. 8, spines lying in different directions; figs. 9–11, spines, magnified; fig. 9 *b*, a portion more magnified.

PLATE LXIII.

Fig. 1 *b*. *Lastræa Bunburii*, m., nat. size; *c*, *d*, magnified. Fig. 1 *a*. *Ficus Falconeri*, m.; fig. 1 *a a*, a portion of the surface of the leaf, magnified; fig. 1 *a a a*, more magnified. Figs. 2–9. *Quercus Lyelli*, m.; fig. 2, apex of the leaf; figs. 3, 8 & 9, base; figs. 4–7, middle piece; fig. 7 *b*, portion of leaf, magnified.

PLATE LXIV.

Fig. 1 *a*, *b*, *c*. *Quercus Lyelli*, m. Fig. 1 *d*. *Phragmites œningensis*, A. Br.? Figs. 2, 3 & 4. *Quercus Lyelli*. Fig. 3 *b* & 5. *Echitonium cuspidatum*, Hr. Figs. 6 & 7. *Ficus Falconeri*, m.

PLATE LXV.

Figs. 1 & 2. *Daphnogene Ungeri*, Hr. Figs. 3–5. *Ficus eucalyptoides*, m. Fig. 6. *Laurus primigenia*, Ung. Figs. 7 & 8. *Ficus Pengellii*; figs. 7 *b* & 8 *b*, a portion of leaf, magnified. Figs. 9–11. *Dryandroides lævigata*, Hr. Fig. 12 *a*. *Dryandroides hakeæfolia*, Ung. Fig. 12 *b*. *Quercus Lyelli*. Fig. 12 *c*. *Echitonium cuspidatum*, Hr. Fig. 13 *a*. *Phragmites œningensis*, A. Br.; 13 *a a*, magnified. Fig. 13 *b*. *Dryandroides lævigata*. Fig. 13 *c*. *Sphæria socialis*, m.; fig. 13 *c c*, magnified.

PLATE LXVI

Figs. 1 & 2. *Quercus Lyelli*, m., restored. Fig. 3. *Ficus Pengellii*, m., restored. Fig. 4. *Ficus Falconeri*, m., restored.

PLATE LXVII.

Figs. 1–8. *Cinnamomum lanceolatum*, Ung., sp. Figs. 9–16. *Cinnamomum Scheuchzeri*, Hr.; fig. 12, branch with the flowers, from Oeningen. Figs. 17 & 18. *Cinnamomum Rossmässleri*, Hr. Fig. 19. *Sclerotium Cinnamomi*, m., magnified; fig. 19 *b*, transverse section.

PLATE LXVIII.

Fig. 1. *Palmacites Dæmonorops*? portion of leaf; fig. 1 *b*, five times magnified. Fig. 2. *Phragmites œningensis*, A. Br.? Fig. 3. *Poacites*, spec. Figs. 4 & 5. *Quercus Lyelli*; fig. 6, bark. Fig. 7. *Dryandroides Banksiæfolia*, Ung., sp.? Fig. 8. *Vaccinium acheronticum*, Ung. Fig. 9. *Andromeda vacciniifolia*, Ung. Figs. 10 & 11. *Andromeda reticulata*, Ett.; fig. 10 *b*, magnified. Figs. 12 & 13. *Cinnamomum Scheuchzeri*; figs. 13 & 13 *c*, flowers; fig. 13 *b*, *d*, magnified. Figs. 14 & 15. *Cinnamomum lanceolatum*. Figs. 16–18. *Eugenia Hœringiana*, Ung. Fig. 19. *Celastrus pseudo-ilex*, Ett. Fig. 20. *Leguminosites areolatus*, m.; fig. 20 *b*, magnified. Fig. 21. *Buprestites Falconeri*, m.; fig. 21 *b*, magnified.

PLATE LXIX.

Figs. 1–8. *Gardenia Wetzleri*; figs. 3–6, seeds, magnified; fig. 7 *a*, *b*, seed-vessel from Samland; fig. 7 *c*, transverse section; fig. 8, fruit from Günzburg. Figs. 9 & 10. *Eucalyptus oceanica*, Ung.? Figs. 11–17. *Nyssa europæa*; figs. 12 *b* & 17 *b*, magnified. Fig. 18. *Nyssa lævigata*; fig. 18 *b*, magnified. Fig. 20–23. *Nyssa striolata*; fig. 20 *b*, magnified. Fig. 24. *Nyssa microsperma*, m.; fig. 24 *b*, magnified. Figs. 25 & 26. *Vitis britannica*, m.; fig. 26 *b*, magnified. Figs. 27 & 28. *Vitis Hookeri*, m., fruit; figs. 29 & 29 *b*, seed; fig. 29 *c*, *d*, magnified; fig. 29 *e*, transverse section. Fig. 30. *Carpolithes scutellatus*, m.; fig. 30 *b*, magnified.

PLATE LXX.

Figs. 1–3. *Anona devonica*, m.; figs. 1 *b* & 2 *b*, transverse section. Figs. 4 & 4 *b*. *Anona cyclosperma*, m. Fig. 5. *Pterocarya denticulata*, O. Web., sp.?; fig. 5 *b* & *c*, magnified. Fig. 6. *Carpolithes Websteri*, Br.; fig. 6 *b*, magnified; fig. 6 *c*, *d*, *e*, portion of the membrane, highly magnified. Figs. 7–14. *Carpolithes Boveyanus*, m.; figs. 8 *b*, 12 *b* & 13 *b*, magnified; figs. 9 *b* & 13 *b*, vertical sections. Figs. 15–23. *Carpolithes nitens*, m.; figs. 17 *b* & 15 *b*, base of the fruit, magnified; fig. 19, transverse section; fig. 19 *b*, magnified; fig. 20, transverse section near the apex; fig. 20 *b*, magnified; figs. 21 & 22, transverse section from the middle of the fruit; fig. 23, many fruits, of natural size. Figs. 24–27. *Carpolithes exaratus*, m.; figs. 24–26, magnified. Figs. 28 & 29. *Carpolithes vinaceus*, m.; fig. 29 *b*, magnified. Figs. 30 & 30 *c*. *Carpolithes lividus*, m.; fig. 30 *c*, magnified. Figs. 32–37. *Nymphæa Doris*, m.; figs. 34 & 36, magnified; fig. 37, highly magnified.

PLATE LXXI.

Fig. 1 *a*, *b*. *Salix cinerea*, Linn.; fig. 1 *c*–*h*. *Salix repens*, Linn.? fig. 1 *k*. *Betula nana*, Linn.; fig. 1 *k k*, magnified. Figs. 2 & 3. *Salix cinerea*, Linn. Figs. 4 & 5. *Salix*, sp. Fig. 6. *Salix repens*, Linn.? Fig. 7 *a*. *Betula nana*, Linn. Fig. 7 *b*. *Salix repens*, Linn.? Figs. 8 & 9, very highly magnified portion of wood.

XLI. *On the Anatomy and Physiology of the Spongiadæ.*—Part III. *On the Generic Characters, the Specific Characters, and on the Method of Examination.*

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While the arrangement of other branches of natural history has occupied the attention of some of the most laborious and talented naturalists of every age, the Spongiadæ appear to have scarcely attracted sufficient attention to excite any writer on natural history to a serious attempt at a systematic classification. This neglect has not arisen from any incapacity for a definite arrangement on the part of the Spongiadæ, as the organic differential characters of the numerous groups into which, by careful examination, they may be readily divided are as varied and as widely removed from each other as are the strikingly distinct and well defined divisions of the Corallidæ; and the number of species I believe to be very much greater than those of the latter class. Of British species alone I am already acquainted with 150 or more; and new ones are continually being discovered by the aid of the dredge. It becomes therefore a matter of necessity that we should classify their permanent varieties of structure, and found on them a series of orders, suborders, and genera, and through these subdivisions become enabled to recognize more readily the very numerous species of these animals which abound in all parts of the world.

De Blainville proposed to include the whole of the Spongiadæ under the designation of Amorphozoa; but this term is objectionable, as all sponges cannot be considered as shapeless—on the contrary, many genera and species exhibit much constancy in their form. Neither can the term be justly applied to their internal structure, as we find in *Grantia*, *Geodia*, *Tethea*, and other genera regular and systematical structures which are very far removed from shapelessness. I have therefore thought it advisable to adopt Dr. Grant's designation of Porifera, a term which embraces the whole of the Spongiadæ, and which is truly descriptive of the most essential general action of the animal's power and mode of imbibing nutriment, which in every species with which I am acquainted is, by a series of minute pores distributed over the external membrane of the sponge.

Besides this universally existent character there are others which are strikingly characteristic of the class, although not so universally prevalent as the porous one. Thus the skeletons of the Spongiadæ are always internal, but in the material and mode of construction they vary to a very considerable extent. Sponges may therefore be defined as fixed, aquatic, polymorphous animals, inhaling and imbibing the surrounding element through numerous contractile pores situated on the external surface; conveying it

through internal canals and ejecting it through appropriate orifices; having an internal flexible or inflexible skeleton composed of either carbonate of lime, silex, or keratode; with or without either of these earthy materials. Calcareous skeletons always spicular. Siliceous skeletons either spicular or composed of solid, laminated, and continuous siliceous fibre.

Propagation by ova, gemmulation, or spontaneous division of its component parts.

Dr. GRANT, in his learned and elaborate "Tabular View of the primary divisions of the Animal Kingdom," published in 1861, has divided the Porifera into three orders, based on principles which I have adopted. The first order is *Keratosa*, in which the skeletons are essentially keratose and fibrous; the second, *Leuconida*, is composed of the calcareous sponges; and the third, *Chalinida*, consisting of the siliceous sponges. I have not adopted the full and precise definition of each of these Orders as given by the learned Professor, as, if the whole of the distinctive characters in the first and third of them were insisted on in the determination of the orders to which many exotic species belong, it would lead in numerous cases to inextricable confusion. The term *Leuconida* is also objectionable, as all calcareous sponges are not white, and colour is at best but a very uncertain character even in the determination of a species; I have therefore adopted the principles of the arrangement of Professor GRANT, with the following modifications of position and descriptions of the characteristics of each order.

1. CALCAREA. Sponges the skeletons of which have as an earthy base carbonate of lime.

2. SILICEA. Sponges in which the earthy base consists of siliceous matter.

3. KERATOSA. Sponges in which the essential base of the skeleton consists of keratose fibrous matter.

While thus assuming the principles of arrangement enunciated by the learned Professor, I have been induced to vary the mode of the disposition of his Orders from the following considerations.

In the highest vertebrated animal types we invariably find the skeleton principally composed of phosphate of lime with a small portion of carbonate of lime and other substances, the whole consolidated by cartilage. As we descend the scale of the Vertebrata we find the salts of lime decrease in proportional quantity until they occur in minute detached patches only, and cartilage becomes the essential base of the skeleton.

In the great tribe of Mollusca we find carbonate of lime prevailing in their shells to the exclusion of phosphate of lime, and in the compound Tunicata we have a structure analogous to that of the cartilaginous tribe of Fishes. In the massive subcartilaginous body of this tribe there is no continuous or connected earthy deposit; this material of the skeleton exists only in the form of detached masses of radiating spicula. As we descend in the animal scale we find carbonate of lime entirely absent, and silex replacing it in the elaborate and beautifully constructed loricæ of the marine and freshwater infusoria.

If we are to reason from these gradations of structure and apply our reasoning to the

Spongiadæ, we should then give precedence to the calcareous sponges as representing in the class the highest order of secretive power; and if we add to these considerations the regularity of structure and function and the full development of ciliary action that exists in *Grantia ciliata* and *compressa* and the allied species, I think it scarcely allows of a doubt that this order should take precedence of the others in an arrangement of the Spongiadæ.

The siliceous sponges naturally follow in succession, and the Keratosæ, as indicated by their imperfect secretive powers and their low order of organization in other respects, would stand the last in the series.

On the Generic Characters of the Spongiadæ.

The foundation of the genera of the Spongiadæ has hitherto been based principally upon form and other external characters of an equally unstable description, and in many instances genera have been named without the slightest attempt to characterize them. As a generic character, form is inadmissible, inasmuch as each variety of it is found to prevail indiscriminately in genera differing structurally to the greatest possible extent.

I will not enter on the history of the genera that have been proposed by previous writers on the Spongiadæ, as the greater portion of those which have been published will hereafter be found to have been adopted, with certain revisions of their characters, in the series of genera I propose to establish, but I shall beg to refer such of my readers as may be desirous of further information on that subject to page 70 of Dr. JOHNSTON'S admirable introduction to his 'History of British Sponges and Lithophytes."

Having thus rejected form and other external characters as the foundation of generic descriptions, we naturally resort to the anatomical peculiarities of the animal for these purposes; and here fortunately we find a variety in structure and form, and a constant adherence to their respective types that admirably adapt them to our purpose.

If any portion of the animal remains whereby we may recognize it as one of the Spongiadæ it is always the skeleton; and it is therefore advantageous to adopt this most persistent portion of the animal as the foundation of our generic descriptions. But this is not the sole reason for such a conclusion, as it is not only the most enduring portion of the animal, but it is also the most undeviatingly regular in the form and arrangement of its component structures. However great may be the variations that exist in size and form between different species of the same genus, or between individuals of the same species, the characteristic tissues of their skeletons are always found to harmonize in their structural peculiarities. It appears, therefore, advisable in these animals, as well as in the higher classes, to select the skeleton as the primary source of generic distinctions. Other portions of the permanent organs may be occasionally resorted to when necessary as auxiliary characters, such as the incurrent and excurrent canals, the intermarginal cavities, the cloaca, and the various modes of reproduction. Each of these characters is of use in generic descriptions to a certain extent; but none of them is absolutely

necessary to the determination of a genus, and occasionally we find one or more of these modes of organization entirely absent; we may therefore consider them not as primary, but rather as secondary or auxiliary generic characters.

I therefore propose to consider the varieties in the construction of the skeleton as the foundation or primary source of division into genera, and to dedicate that portion of the animal especially to that purpose, the auxiliary or secondary characters being resorted to only when required to aid and assist the primary ones; and it is only to a very limited extent that they are in reality available. Thus the cloaca in the Order Calcarea becomes a very important means of generic distinction, and in some cases in the Order Keratosa it is also a prominent character, while in Silicea it is generally absent. In some species of this order, as in *Alcyoncellum*, *Polymastia*, and *Halyphysema*, it assumes a normal character, while in several species of *Halichondria*, as in *H. panicea*, it assumes very striking proportions in excessively developed specimens, whilst in others it is either an occasional, uncertain, and progressive organ, or is altogether absent.

The mode of propagation is also an uncertain character. Thus in *Tethea cranium* we find it to be by internal gemmulation, in *T. Lyncurium* by external gemmules, and in other species of the genus no gemmules of any description have hitherto been detected. In *Geodia*, *Pachymatisma*, and *Spongilla* the general structure and mode of disposition of the ovaria render them valuable auxiliary generic characters, but in other cases they are of little or no value.

The intermarginal cavities are available as generic characters in *Geodia* and the nearly allied species; and in the same sponge the relative position of the connecting spicula form good distinctive characters in the genera *Geodia*, *Ecionemia*, and also some of the siliceo-fibrous sponges. In *Alcyoncellum*, *Polymastia*, and *Geodia* the position and appendages of the oscula are also available; but generally speaking those organs are so mutable as to render them of little value as generic characters.

The following tabular view of the arrangement I propose to adopt will perhaps render the details regarding the distinctive characters and natural affinities of the genera more readily comprehensible.

Tabular View of Systematic Arrangement.

Class.	Order.	Suborder.	Genera.
PORIFERA.	I. CALCAREA.		Grantia, *Fleming.* Leucosolenia, *Bowerbank.* Leuconia, *Grant.* Leucogypsia, *Bowerbank.*
	II. SILICEA.	1. Spiculo-radiate skeletons	Geodia, *Lamarck.* Pachymatisma, *Bowerbank.* Ecionemia, *Bowerbank.* Alcyoncellum, *Quoy et Gaimard.* Polymastia, *Bowerbank.* Halyphysema, *Bowerbank.* Ciocalypta, *Bowerbank.* Tethea, *Lamarck.* Halicnemia, *Bowerbank.* Dictyocylindrus, *Bowerbank.* Phakellia, *Bowerbank.* Microciona, *Bowerbank.* Hymeraphia, *Bowerbank.* Hymedesmia, *Bowerbank.*
		2. Spiculo-membranous skeletons	Hymeniacidon, *Bowerbank.*
		3. Spiculo-reticulate skeletons	Halichondria, *Fleming.* Hyalonema, *Gray.* Isodictya, *Bowerbank.* Spongilla, *Linnæus.*
		4. Spiculo-fibrous skeletons	Desmacidon, *Bowerbank.* Raphyrus, *Bowerbank.*
		5. Compound reticulate skeletons	Diplodemia, *Bowerbank.*
		6. Solid siliceo-fibrous skeletons	Dactylocalyx, *Stutchbury.*
		7. Canaliculated siliceo-fibrous skeletons	Farrea, *Bowerbank.*
	III. KERATOSA.	1. Solid non-spiculate kerato-fibrous skeletons	Spongia, *Linnæus.* Spongionella, *Bowerbank.*
		2. Solid semispiculate kerato-fibrous skeletons	Halispongia, *Blainville.*
		3. Solid entirely spiculate kerato-fibrous skeletons	Chalina, *Grant.*
		4. Simple fistulo-fibrous skeletons	Verongia, *Bowerbank.*
		5. Compound fistulo-fibrous skeletons	Auliskia, *Bowerbank.*
		6. Regular semi-areno-fibrous skeletons	Stematumenia, &c., *Bowerbank.*
		7. Irregular and entirely areno-fibrous skeletons	Dysidea, *Johnston.*

Order I. CALCAREA.

The number of species of calcareous sponges that are known is comparatively so small, and the four genera into which I have divided them are naturally so well characterized, as to render the establishment of suborders unnecessary. Hereafter, when we are acquainted with a greater number of species, and other varieties of organization become known, the genera now established may become the types of suborders, for which office their distinctly different modes of construction render them eminently efficient.

Although the calcareous structure of the species of this order appears to entitle it to precedence in the arrangement of the Spongiadæ, it does not maintain in the structure of its skeleton throughout the whole of the genera the same high type of formation

that is exhibited in *Grantia compressa* and the allied species, and we observe a progressive decline in regularity of structure in its genera very analogous to what we find existing among the Halichondroid tribe of sponges; but in this respect they only follow the same laws of gradual degradation that obtain in every other class of created beings; and therefore this gradual decline in regularity of structure should not militate against the claim of even the lowest in organization of the tribe from taking precedence of the siliceous sponges.

Dr. GRANT was the first naturalist who decided that the spicula of a certain group of small sponges were composed of carbonate of lime, and he separated them accordingly from those the spicula of which were siliceous, and assigned to them the generic name of *Leucalia* (Edinburgh Encyclopædia, vol. xviii. p. 844); and subsequently, in his 'Outlines of Comparative Anatomy,' he changed that name to *Leuconia*. In 1828 Dr. FLEMING gave to the group the name of *Grantia*, in compliment to the learned naturalist who had first pointed out their peculiar structure.

A careful examination of the British species of this Order will very soon satisfy a naturalist that there are at least four distinct forms in the organization of the skeleton, and that each is fully entitled to generic distinction. Thus in *Grantia ciliata* and *compressa*, Johnston, we find the sponge to be constructed of a series of cells, each having separate parietes, and extending from the dermal surface to near the inner surface of the sponge, where they discharge the fæcal streams into a common cloacal cavity. In *Grantia botryoides*, Johnston, the system of cells is entirely wanting; the sponge is composed of a single thin stratum of membranous structure and spicula, surrounding a large cylindrical cloacal cavity, from the terminations of which the fæcal streams are discharged. In *Grantia nivea*, Johnston, we find the sponge massive and irregular in form, containing numerous capacious cloacal cavities, each terminated by a single large mouth, the interstitial structures between the sides of these great cavities and the dermal surfaces of the sponge consisting of irregularly disposed membranes and spicula, permeated by contorted interstitial cavities, terminating in simple orifices or oscula in the sides of the great fæcal cavity into which they discharge their excurrent streams; and in *Leucogypsia Gossei*, Bowerbank, MS., the sponge is massive, without cloaca, formed of irregularly disposed membranous tissues and spicula, and with oscula at the external surface, thus simulating to a great extent the mode of structure of the Halichondroid tribes of sponges.

The sponges of this Order appear to possess a high degree of vital power, and I have rarely failed in finding the excurrent orifices in vigorous action in either *Grantia compressa*, *ciliata*, or *botryoides* when recently taken from the sea. In *G. compressa*, especially, I have often observed the inhalant and exhalant actions remarkably vigorous; and if a drop of water containing finely comminuted indigo be mixed with the water in which they are immersed, they will become deeply tinctured with it in a very few seconds. This vigorous action is accounted for by the highly developed ciliary system, which may be readily seen in action if the sponge be carefully split open and immersed in fresh cold

sea-water, and examined with a power of about five or six hundred linear by transmitted light. The cilia will be seen in rapid action just within the oscula which terminate each of the large angular interstitial cells of the sponge. This action, and the mode of the disposition of the cilia within the cells, I have described at length in the Transactions of the Microscopical Society of London, vol. iii. p. 137, plate 19. In accordance with these variations in structure I purpose dividing the British species into four genera.

Class **PORIFERA**, Grant.

Order I. CALCAREA.

Genera. *Grantia.*
Leucosolenia.
Leuconia.
Leucogypsia.

Grantia, Fleming.

Sponge furnished with a central cloaca, parietes constructed of interstitial cells, more or less regular and angular in form, disposed at right angles to the external surface, and extending in length from the outer to very near the inner surface of the sponge, where each terminates in a single osculum.

Type, *Grantia compressa*, Johnston.

The cloaca varies in its form and proportion. In some species it has invariably one large terminal mouth, while in others it is furnished with several mouths, from which the excurrent fæcal streams are discharged.

The interstitial structures of the sponges of this genus assume a greater amount of regularity than is found to exist in any other genera of these animals. The whole of the parietes of the sponge are formed of somewhat angular cells, the sides of which belong to the individual cell, and are not common to the adjacent cells. The length of the cells in proportion to their diameter varies in different species, and also in the same species in proportion to the age and thickness of the parietes of the sponge. The cell-walls are formed of comparatively stout transparent membrane, strengthened and supported by numerous triradiate spicula; and the whole length of the cell, from the inner edge of the osculum to near the outer surface of the sponge, is closely studded with tessellated nucleated cells, each of which is furnished with a long attenuated cilium. Each interstitial cell terminates in a single osculum, slightly within the plane of the inner surface of the sponge. I do not remember to have ever seen these oscula entirely closed. When the inhalant action of the sponge is in vigorous operation, the excurrent streams may be seen issuing from them with considerable force, and the cilia appear in action immediately within them.

Hitherto the mouths of the great cloacal cavity of the sponges of this tribe have been described as oscula; but if we carefully examine the structure of these and similarly

formed sponges, we shall find in all cases that those organs exist only on the inner surface of the great cloacal cavities.

The construction of the interstitial cells is best demonstrated in a longitudinal section of a dried specimen of *Grantia ciliata*, mounted in Canada balsam; and in a specimen so prepared, spaces are seen between the cells, which are often nearly half the size of the cells. These spaces are most probably produced by the contraction of the tissues induced by the mode of the preparation of the object, and do not exist in the living sponge; but they serve admirably to demonstrate the fact that each interstitial cell has its own special parietes, and that the divisions between the cells are not common to adjacent cells. Plate LXXII. fig. 1, and (Part II.) Plate XXXIII. figs. 1 & 2.

Leucosolenia, Bowerbank.

Grantia, Fleming and Johnston.

Sponge fistular, formed of a single layer of triradiate and other spicula surrounding a large central cloaca, which extends into all parts of the sponge.

Type, *Grantia botryoides*, Fleming.

The structure of *Grantia botryoides*, Fleming, differs essentially from that of *Grantia compressa* of that author, inasmuch as there is a total absence of the interstitial cells which are so characteristic of the latter sponge; and its structure is equally discrepant when compared with that of *Grantia nivea* of Fleming; for although it possesses cloacæ in common with that species, it has no approximation whatever to the massive Halichondroid form of the substance of that sponge. On the contrary, its parietes consist of a single thin layer of spicula and membranous tissues surrounding a large central sinuous cloaca. Plate LXXII. fig. 2.

Leuconia, Grant.

Grantia, Fleming and Johnston.

Sponge furnished with cloacæ, one or more. Parietes of sponge formed of a mass of irregularly disposed interstitial membranes, and triradiate and other spicula; permeated by sinuous excurrent canals, the oscula of which are irregularly disposed over the surfaces of the cloacæ.

Type, *Grantia nivea*, Fleming.

Grantia nivea of Dr. Fleming is very different in its structure from either *G. compressa* or *ciliata*, or of *G. botryoides* of that author. It has not the regular interstitial structure of either of the first two, nor the simple fistulose form of the latter one, but, with the exception of the form of the spicula, it closely simulates the structural character of the siliceous genus *Halichondria*, while it is allied with the before-named calcareous sponges by the possession of cloacæ. In consequence of these marked differences in the structure of the skeleton, I have separated it from *Grantia* as defined by Dr. Fleming, and constituted it a genus, adopting the term *Leuconia*, which was proposed by Dr. Grant as a general designation of the whole tribe of calcareous sponges. Plate LXXII. fig. 3.

LEUCOGYPSIA, Bowerbank.

Sponge massive, without cloacæ; formed of irregularly disposed membranous tissues and spicula. Oscula at the external surface.

The sponges of this genus are still further removed in structural character from the more highly organized genera of calcareous sponges *Grantia* and *Leucosolenia* than the genus *Leuconia* is. In the arrangement of the interstitial membranes, and the mode of dispersion on them of the skeleton-spicula, there is a manifest similitude to the structural peculiarities of the genus *Hymeniacidon* among the Silicea, and we find a corresponding simplicity in the characters of the spicula, in *Leucogypsia* the type of this genus. There are no regularly determined cloacæ projected from the surface as in *Leuconia*; and the excurrent canals of the sponge merge into each other, until they unite in one large canal immediately beneath the osculum, in the manner generally prevailing in the great mass of Halichondroid sponges. These large canals have defensive spicula similar in structure to those of the other genera of calcareous sponges. The only known British species of this genus is *L. Gossei*, Bowerbank, MS.; but I am acquainted with an exotic species, *L. algoaensis*, Bowerbank, MS., which is not uncommon on specimens of Zoophytes and Fuci from Algoa Bay and its neighbourhood. Plate LXXII. fig. 4.

Synopsis of the Suborders of the SILICEA *and* KERATOSA.

Order II. SILICEA.

Suborder I. Spiculo-radiate skeletons. Not reticulate. Composed of spicula radiating in fasciculi or separately from the base or axis of the sponge.

1. *Geodia*, Lamarck.
2. *Pachymatisma*, Bowerbank.
3. *Ecionemia*, Bowerbank.
4. *Alcyoncellum*, Quoy et Gaimard.
5. *Polymastia*, Bowerbank.
6. *Halyphysema*, Bowerbank.
7. *Ciocalypta*, Bowerbank.
8. *Tethea*, Lamarck.
9. *Halicnemia*, Bowerbank.
10. *Dictyocylindrus*, Bowerbank.
11. *Phakellia*, Bowerbank.
12. *Microciona*, Bowerbank.
13. *Hymeraphia*, Bowerbank.
14. *Hymedesmia*, Bowerbank.

Suborder II. Spiculo-membranous skeletons. Composed of membranous structure, having spicula irregularly dispersed on their surfaces.

Hymeniacidon, Bowerbank.

Suborder III. Spiculo-reticulate skeletons. Skeletons continuously reticulate in structure, but not fibrous.

1. *Halichondria*, Fleming.
2. *Hyalonema*, Gray.
3. *Isodictya*, Bowerbank.
4. *Spongilla*, Linnæus.

Suborder IV. Spiculo-fibrous skeletons. Regularly fibrous. Fibres filled with spicula.

1. *Desmacidon*, Bowerbank.
2. *Raphyrus*, Bowerbank.

Suborder V. Compound reticulate skeletons, having the primary reticulations fibro-spiculate, and the interstices filled with a secondary spiculo-reticulate skeleton.

Diplodemia, Bowerbank.

Suborder VI. Solid siliceo-fibrous skeletons, reticulate. Fibres composed of concentric layers of solid silex; without a central canal. Reticulations unsymmetrical.

Dactylocalyx, Stutchbury=*Iphiteon* of the Museum at the Jardin des Plantes, Paris.

The structure of the fibre in this suborder of siliceo-fibrous sponges is equivalent to that in the first suborder of the third order, Keratosa.

Suborder VII. Canaliculated siliceo-fibrous reticulated skeletons. Fibres composed of concentric layers of solid silex, with a continuous central canal. Reticulations symmetrical.

Farrea, Bowerbank.

The construction of the fibre of the skeletons of this suborder of siliceo-fibrous sponges is the equivalent of the fibrous structure of the fourth suborder of the third order, Keratosa.

Order III. KERATOSA.

Suborder I. Solid non-spiculate kerato-fibrous skeletons.

1. *Spongia*, Linnæus.
2. *Spongionella*, Bowerbank.

No spicula are secreted in any of the parts of the sponges of this suborder.

Suborder II. Solid semispiculate kerato-fibrous skeletons. Skeleton partially symmetrical; primary lines of fibre radiating from the proximal to the distal parts of the sponge; fibres containing spicula. Secondary lines of fibres unsymmetrical, destitute of spicula.

The Bahama sponges of commerce are most of them members of this suborder.

Halispongia, Blainville.

Suborder III. Skeletons kerato-fibrous; fibres solid, entirely interspiculous. Skeleton symmetrical.

Chalina, Grant.

In this suborder the keratode is the primary material in the structure of the fibre, and the spicula the secondary or auxiliary agent. The reverse is the case in the spiculo-fibrous tissues of the fourth suborder of Order II. Silicea.

Suborder IV. Simple fistulo-fibrous skeletons. Cavity of the fibre simple, central, and continuous.

Verongia, Bowerbank.

Spongia fistulosa, Lamarck.

The genus *Verongia* was described by me in the Annals and Magazine of Natural History for May and December 1845.

The same relative differences exist between the fibrous structures of the suborders six and seven of the second order, Silicea, that we observe between those of the first and fourth suborders of the third order, Keratosa.

Suborder V. Compound fistulo-fibrous skeletons. Central cavity of the fibre single and continuous, having secondary cæcoid branches radiating from it at nearly right angles.

Auliskia, Bowerbank.

This genus was described by me in the Annals and Magazine of Natural History for May and December 1845.

Suborder VI. Regular semi-areno-fibrous skeletons. Skeleton regularly areno-fibrous, having a well-defined central line of grains of extraneous matter within the fibres.

Stematumenia, Bowerbank.

In the sponges of this suborder the extraneous material is subordinate to the keratose fibre, in which it exists in the form of a central line of sand or other extraneous matters, constituting an axial line in the fibre surrounded by a thick coat of pure keratode. The axial line of sand is generally confined to the primary fibres of the skeleton, the secondary ones being usually without it. A portion of the commonest Bahama sponges of commerce belong to this order.

Suborder VII. Irregular and entirely areno-fibrous skeletons. Skeleton irregularly areno-fibrous, having the skeleton-fibre filled from the centre to the surface with grains of extraneous matter.

Dysidea, Johnston.

In the skeletons of the sponges of this suborder the keratode appears subordinate to the extraneous matter; the fibres frequently appearing to consist almost entirely of sand.

On the Arrangement of the Genera.

The genus *Halichondria*, as established by Fleming and adopted by Dr. Johnston, when applied to the arrangement of exotic as well as British species, embraces so wide a range as to afford little or no assistance in the determination of species. Under this designation every known sponge would be arranged having silex as the earthy basis of its skeleton, however varied their anatomical structure might be, excepting the few species contained in the genera *Geodia*, *Tethea*, and *Spongilla*.

Dr. Johnston, in his 'History of British Sponges,' has divided the British species into

three sections, dependent on their form, a character so mutable among the Spongiadæ, as to render it of little value, under any circumstances, when unaccompanied by structural peculiarities. I have therefore thought it advisable to distribute the genera included in the order Silicea among seven suborders, founded on the most striking peculiarities of the structure of the skeleton.

The first of these will consist of sponges having spiculo-radiate skeletons. Skeletons not reticulated, but composed of spicula radiating in fasciculi or separately from the base or axis of the sponge. This order will contain as many as fourteen distinct genera, the whole of which have skeletons the spicula of which are arranged in radial order. The mode of the radiation in these fourteen genera is not precisely the same, but they form three closely according groups, of which the leading genus of each of the first two may be considered as the type.

1. *Geodia*, Lamarck.
2. *Pachymatisma*, Bowerbank.
3. *Ecionemia*, Bowerbank.
4. *Alcyoncellum*, Quoy et Gaimard.
5. *Polymastia*, Bowerbank.
6. *Halyphysema*, Bowerbank.
7. *Ciocalypta*, Bowerbank.

The second group contains:

1. *Tethea*, Lamarck.
2. *Halicnemia*, Bowerbank.
3. *Dictyocylindrus*, Bowerbank.
4. *Phakellia*, Bowerbank.

In the whole of the first two groups, excepting *Halyphysema*, the skeleton-radiations are fasciculated to a greater or a less amount in the different genera.

The third group will comprise:

1. *Microciona*, Bowerbank.
2. *Hymeraphia*, Bowerbank.
3. *Hymedesmia*, Bowerbank.

The most striking general character in these three genera is the extremely thin coating-form of the sponge, and the radiation of the skeleton-spicula, either singly or in an irregularly fasciculated form, from a common basal membrane, the thickness of the sponge in some of the species being less than the length of one of the radiating skeleton-spicula.

Order II. SILICEA.

Suborder I. Spiculo-radiate skeletons. Not reticulate. Composed of spicula radiating in fasciculi or separately from the base or axis of the sponge.

Geodia, Lamarck.

Skeleton: spicula fasciculated, radiating from the base or central axis of the sponge to the surface. Dermis crustular, furnished abundantly with closely packed ovaria. Ovaria siliceous, composed of cuneiform spicula, firmly cemented together by silex, in lines radiating from the centre of the ovary. Pores furnished with œsophageal tubes *

* *i. e.* tubes resembling in their office the œsophageal tubes of the higher animals. The expression "pyloric valve" used further on is to be understood in a similar sense.

terminating in the distal extremity of the intermarginal cavities. Intermarginal cavities separate, symmetrical, subcylindrical; each furnished with a membranous valve at its proximal extremity.

The genus, as described by Lamarck*, is so loosely characterized that I have thought it better to reconstruct it entirely than to endeavour to amend it. I have therefore given a new series of characters, founded solely on its structural and organic peculiarities. I am acquainted with seven species, all of which perfectly agree in the essential generic characters as thus constructed.

The type specimen of Lamarck's *Geodia gibberosa* in the Museum of the Jardin des Plantes of Paris, the organization of which, through the kindness of Professors Milne-Edwards and Valenciennes, I have had an opportunity of thoroughly examining, is unfortunately in so deteriorated a condition in many respects, and especially in regard to the dermal membrane and pores, that I have been induced to select *G. Barretti* from which, to a great extent, to describe the interesting and highly organized structures of this genus; and I have the advantage also in this species of having a portion of a specimen which has never been deteriorated by drying, having been pickled in strong salt and water immediately on being taken from the sea, by my friend Mr. M^{c}Andrew, and in this state it closely resembles a mass of somewhat indurated animal liver.

The skeleton is composed of continuous fasciculi of stout long spicula, which in massive specimens radiate from the base to the outer surface of the sponge, or, if the species be of an elongated form, from the central axis to the circumference, where in either case they terminate at the inner surface of the crustular dermis, intermixing with, and being firmly cemented to, the shafts of the expando-ternate connecting spicula, which are attached to and firmly support the inner surface of the crustular dermis.

The organization of this external crust is exceedingly interesting. The outer surface is composed of a uniform thin pellucid dermal membrane, perforated with innumerable minute pores, variable in their diameter, and apparently possessing the power of opening or closing at the will of the animal. Immediately beneath the dermal membrane there is a stratum of sarcode of variable thickness in different species; and this stratum is permeated by numerous short canals, connecting the external pores with the intermarginal cavities which occupy, at nearly equidistant points, the thick stratum of ovaria forming the inner layer of the crustular dermis. In dried specimens, the positions of the intermarginal cavities are usually indicated on the surface of the sponge by a series of dimples or pits, frequently assuming, by the contraction of the dermal membrane, more or less of a stellated appearance. The proximal extremities of these organs is at the inner surface of the stratum of ovaria, and the distal extremities at the outer surface of the same stratum; and this termination has usually a greater diameter than the proximal end, which is furnished with a stout contractile diaphragm or pyloric valve.

* Polyparium liberum, carnosum, tuberiforme, intùs cavum et vacuum, in sicco durum; externâ superficie undique porosâ. Foramina poris majora in areâ unicâ orbiculari et laterali observata. (Lamarck, Anim. s. Vert. 2de édit. ii. p. 593.)

The expando-ternate spicula, which are situated at the distal extremities of the radial fasciculi of the skeleton, diverge slightly from each other from their basal extremities, so that their triradiate heads, when firmly cemented to the inner surface of the ovarian stratum, form a strong and regular siliceous network, the points of the radii of each being cemented by keratode to those of its next neighbour; and within the area of each of these meshes of the network there is the proximal end of an intermarginal cavity, the diaphragm of which frequently occupies the greater portion of the area, having a much greater diameter than that of the proximal orifice of the cavity, so that when fully opened its orifice is quite equal to that of the intermarginal cavity. The ovaries vary considerably in size in different species. In the adult and prolific condition they have the form of a strong, thick-shelled, more or less globose ovarium, having a funnel-shaped orifice at the apex, which communicates with the central cavity, which, in the prolific state, is filled with closely-packed minute vesicular bodies, very similar in appearance to those contained in the ovaria of the Spongilladæ, but apparently more minute. In this condition of the ovary its parietes are formed of acutely cuneiform spicula, firmly cemented together by siliceous matter, the united apices forming the inner surface of the ovarium, while the united truncate bases form the external surface. In the early and immature state of the ovaria these truncated bases are not produced, and the young ovary has its outer surface bristling with pointed spicula, which are most acute in the youngest specimens, and become gradually more obtuse as they approach maturity. After the prolific contents of the adult ovary have been liberated, the internal cavity is gradually filled up by the extension inwards of the apices of the cuneiform spicula, until it becomes eventually a solid body; and a similar secretion of siliceous matter is also frequently continued at the outer surface until it often assumes an irregular tuberous and quite abnormal appearance.

The ovarian stratum of the crustular dermis is principally composed of exhausted solid ovaria; but occasionally near the outer surface of the stratum a few prolific ones may be observed, but the greater number of these bodies and of those in an early stage of development are situated amid the deeply-seated portions of the sponge, scattered irregularly over the sarcodous membranes and deeply immersed in the sarcode. In the young state they each appear to be surrounded by a firm stratum of sarcode, which, from its perfectly smooth and circular form, is apparently contained within a proper membrane, but in the fully developed and in the exhausted ovaria this sarcodous envelope is not observable. This description of the organization of the genus will apply equally well to any one of the seven species with which I am acquainted, and also to the nearly allied genus *Pachymatisma*, excepting the mode of the arrangement of the skeleton in the latter.

Both the type specimens of *Geodia* in the Museum at the Jardin des Plantes appear to have had large central cavities; but I have not found similar excavations in other species of the genus, excepting in one instance, a *Geodia* from Port Elliot, Australia; the internal surface in each of the three cases presents precisely the same appearance—a simple irregularly matted surface of spicula and membranes without any thickening of

the tissues, and differing in no respect from the surfaces of any of the smaller internal cavities of the sponge. I am therefore inclined to consider such excavations as abnormal occurrences, which are not entitled to be considered as of either generic or specific value. Part II. Plate XXXII. figs. 2, 3, & 4; and Plate LXXII. fig. 5.

PACHYMATISMA, Bowerbank.

Skeleton composed near the external surface occasionally of short fasciculi of siliceous spicula, disposed in lines at about right angles to the surface of the sponge. Central portion of the sponge unsymmetrical. Dermis crustular, furnished abundantly with closely packed ovaria. Ovaria siliceous, formed of cuneiform spicula, firmly cemented together in lines radiating from the centre of the ovary. Pores furnished with œsophageal tubes, terminating in the distal extremity of each intermarginal cavity. Intermarginal cavities symmetrical, subcylindrical, with a pyloric valve at the proximal end of each.

Since the first publication of my description of the sponge on which this genus is founded in the Synopsis Spongiarum of Dr. JOHNSTON'S 'History of British Sponges,' p. 243, I have found it necessary to base the generic characters of the Spongiadæ on the structural peculiarities of the skeleton and reproductive organs. I have therefore reconstructed the character of the genus in accordance with this rule.

This genus is closely allied to *Geodia* in its organic structure, but the difference in the arrangement of the skeleton readily distinguishes them. The general aspect of the species of each genus is also strikingly distinct. I am acquainted with six species of *Geodia* and three of *Pachymatisma*; and in every case the species may be readily referred to its proper genus even by its general aspect. All the species of either genus have a crustular dermis, and the structures of the ovaria are also alike in each. I have described the anatomical peculiarities of the latter organs so fully in the description of the generic characters of *Geodia* as to render it unnecessary to treat of them here. Plate LXXII. fig. 6.

ECIONEMIA, Bowerbank.

Sponge having a strong axial column or centre of closely packed siliceous spicula disposed in lines parallel to the long axis of the sponge, from which axial column or centre a peripheral system of spicula radiates at about right angles. Distal ends of the radii furnished more or less with ternate connecting spicula, the radii of which are disposed immediately beneath the dermal membrane.

This genus differs from *Dictyocylindrus* in having the axial column composed of a dense mass of parallel spicula instead of a column formed of an open network of spicula; and the peripheral system is also different, inasmuch as it is essentially a portion of the interstitial system of the sponge, and not more especially a defensive system as it appears in *Dictyocylindrus*, in no species of which genus have there ever yet been found ternate spicula at the surface, while in *Ecionemia acervus*, the type species of the genus, they are abundant.

The structure of the peripheral system exhibits a close alliance with the genera *Pachymatisma* and *Tethea*. *Ecionemia* differs from *Geodia* and *Pachymatisma* in the total absence of the siliceous ovaries, and of the crustular dermal coat formed principally of those bodies in the last-named genera. There are also no cylindrical valvular intermarginal cavities, and the ternate apices of the connecting spicula appear always to be applied to the inner surface of the dermal membrane. This arrangement of the tissues therefore forms a natural transition from *Pachymatisma* to *Tethea*, in some species of which genus the ternate spicula are found without the dermal membrane in the porrecto-ternate form, and are adapted to defensive purposes, while in others they occur immediately beneath it as patento-ternate connecting spicula. I have therefore assigned this genus a position between *Pachymatisma* and *Dictyocylindrus*. Plate LXXIII. fig. 1.

We have no British species of this genus; the type species, *Ecionemia acervus*, Bowerbank, MS., is in the Museum of the Royal College of Surgeons of London.

On the Genus ALCYONCELLUM, Quoy *et* Gaimard (*Euplectella*, Owen).

Professor OWEN, in his paper on *Euplectella aspergillum*, Owen, communicated to the Zoological Society January 26, 1841, and published in the Transactions of the Zoological Society of London, vol. iii. part 2. p. 203, pl. 13, appears to have fallen into a singular number of errors in the course of his description of this beautiful sponge. He has, in the first place, designated it as belonging to the Alcyonoid family, apparently only because it is cylindrical in form and reticulate in structure, but without the slightest reference to the polyps that must necessarily characterize an Alcyonium; and he proceeds in his description to describe the base of the sponge as its apex and the apex as its base. The author then notices the first specimen of this genus that was made known to us by MM. QUOY and GAIMARD, in the 'Zoologie de l'Astrolabe,' 8vo, 1833, p. 302, planches fol. Zoophytes, pl. 26. fig. 3, but unfortunately mistakes the generic name *Alcyoncellum*, applied to the sponge by the French authors, for *Alcyonellum*; and having mistaken its name, its base, and its apex, he proceeds to reason on its generic characters thus:—"If the basal aperture of the cone were open, the resemblance to some of the known reticulate Alcyonoid sponges would be very close, especially to that called *Alcyonellum gelatinosum* by M. DE BLAINVILLE, 'Manuel d'Actinologie,' 8vo, 1834, p. 529 (*Alcyonellum speciosum*, Quoy et Gaimard): its closure by the reticulate convex frilled cap, in the present instance, establishes the generic distinction; and in the exquisite beauty and regularity of the texture of the walls of the cone, the species surpasses any of the allied productions that I have yet seen or found described. I propose, therefore, to name it *Euplectella aspergillum*." In note 5 appended to this paper, Professor OWEN also says, "If the recognition of the generic or specific identity of the specimen here figured be impracticable by reason of its mutilated condition, the generic name applied to it cannot be adopted while the Lamarckian genus of freshwater polyps, *Alcyonella*, is retained in Zoology." Now as it is manifest that the reasoning of

Professor Owen in favour of his proposed genus *Euplectella* is based, not upon one only, but upon a series of errors; and as he has not attempted to characterize his own genus, while that of *Alcyoncellum*, Quoy et Gaimard, is regularly described in the 'Histoire Naturelle des Animaux sans Vertèbres' by Lamarck, 2nd edit. vol. ii. p. 589, printed in 1836, it is evident that the generic name of the French authors must take precedence of that proposed by Professor Owen.

The following is the generic description of MM. Quoy et Gaimard:—

"Genre Alcyoncelle (*Alcyoncellum*).

Spongiaire lamelleux, dont la charpente est formée de filets très déliés, accolés les uns aux autres et entre-croisés de manière à former des mailles nombreuses, arrondies, assez régulières, et semblables à celles d'une dentelle."

In this generic description the material of which the sponge is formed is not in the slightest degree indicated, and the description of its structural peculiarities is so general that it will apply equally well to almost every known fistulose sponge. I have therefore thought it necessary to arrange the sponges of this genus with their congeners in material and mode of construction, and to reconstruct the generic characters so as to endeavour to limit the genus within definite bounds. I propose therefore to substitute the following characters for those of the French authors.

Alcyoncellum, Quoy et Gaimard.

Euplectella, Owen.

Sponge fistulate; fistula single, elongate, without a massive base. Skeleton: primary fasciculi radiating from the base in parallel straight or slightly spiral lines; secondary fasciculi at right angles to the primary ones. Oscula congregated, with or without a marginal boundary to their area.

The congregation of the oscula in *Alcyoncellum corbicula* and *A. aspergillum* is not a character peculiar to those sponges. A similar mode of arrangement exists in several species of *Geodia*. In *G. gibberosa*, in the Museum of the Jardin des Plantes at Paris, they are congregated in an area with a well-defined boundary, and in specimens of *G. Barretti* in my possession they are situated in deep depressions or cavities on the surface of the sponges; and these cavities or areas are not uniform in either shape or size; so we may infer that the presence in some species of *Alcyoncellum* of a well-defined marginal boundary to the oscular area, and its absence in other species, amounts to a specific difference rather than to a generic distinction; but in either case the oscula are congregated at the distal extremity of the sponge, and the areas of its parietes are the inhalant portions of the animal. The inhalation and exhalation of water is precisely on the same principle as that which obtains in *Grantia ciliata*; the whole of the parietes are appropriated to inhalation, the incurrent streams are passed through the interstitial cavities and discharged into a common cloaca, and the effete stream ejected at the distal

extremity of the sponge,—the essential difference being that in *Grantia* the distal end of the cloaca is open, and in *Alcyoncellum* it is partially closed by a cribriform veil, the orifices of which appear to be the true oscula of the sponge. And this opinion is justified by the structure of the numerous cloacæ in the closely-allied genus *Polymastia*, where we find the orifices through which the incurrent streams are poured into the cloaca permanently open.

All the known species of this genus appear to consist of a single fistulose body, and some of them are apparently of a parasitical habit. *Alcyoncellum aspergillum* especially is furnished with numerous recurvo-quaternate spicula at its base, by which it attaches itself to sponges or other bodies. These prehensile organs do not appear in all the species of the genus; and in one perfect and beautiful specimen in the Museum of the Jardin des Plantes at Paris the base is closed, and is entirely destitute of prehensile spicula. The attachment of the sponge is partly, on one side, in the form of a thick incrustation, and partly, close to the base, by a similar patch of thickened tissue. There is also another striking difference in its structure; and that is, the absence of the raised margin to the oscular area at the apex of the sponge. In other structural characters it agrees exceedingly closely with *A. aspergillum*.

POLYMASTIA, Bowerbank.

Skeleton a basal mass; central portion consisting of a plexus of contorted anastomosing fasciculi, resolving themselves near the surface into short straight bundles disposed at nearly right angles to the surface. Oscula congregated, elevated on numerous long fistulæ. Fistulæ composed of numerous parallel fasciculi, radiating from the base to the apex of each in straight or slightly spiral lines. Plate LXXIII. fig. 2.

This genus is closely allied to *Alcyoncellum*, Quoy et Gaimard, the principal difference being that in the latter the sponge always consists of a single fistula, while in the former it is constructed of a basal mass from which numerous fistulæ emanate. The fistular organs in each genus very closely resemble each other in their form and structure. Besides these structural differences, there are others, of a less striking description, that strongly indicate the necessity for generic separation. Thus in *Alcyoncellum corbicula*, in the Museum at Paris, and *Euplectella aspergillum*, Owen, there are an abundance of interstitial spicula of rectangulated sexradiate forms, which are very characteristic of those species, while the British species of *Polymastia* with which we are acquainted appear to be totally destitute of these complicated and beautiful forms of spicula. I have therefore thought it desirable, notwithstanding the close agreement that exists in the structure of their fistulæ, that a generic distinction should be established between them.

Halichondria mammillaris, Johnston, is the best type of the genus *Polymastia*. The whole of the parietes of these elongated fistulæ are inhalant. In some specimens of *P. mammillaris* dredged in Vigo Bay by my friend Mr. M°ANDREW, the open pores are exceedingly numerous, and the exhalant organs are as distinctly shown to be confined to the distal extremities of the fistulæ.

HALYPHYSEMA, Bowerbank.

Sponge consisting of a hollow basal mass from which emanates a single cloacal fistula. Skeleton: spicula of the base disposed irregularly; spicula of the fistula disposed principally in lines parallel to the long axis of the sponge, without fasciculation.

In its form and habit the type of this genus closely resembles *Polymastia brevis*; but the total absence of fasciculi in its construction at once marks it as a distinct genus, although a closely allied one. The type species, *H. Tumanowiczii*, is remarkable as being the smallest known British sponge; it rarely exceeds a line in height. The base of the sponge resembles in form the half of an orange cut at right angles to its axis; and the fistular cloaca is usually dilated at its distal extremity. I have been unable to detect either oscula or pores in any of the numerous specimens I have examined; but, from the general accordance in structure with the genera *Alcyoncellum* and *Polymastia*, there is a strong presumption that the oscula will prove to be congregated at the distal extremity of the cloacal fistula, as in those genera. Plate LXXIII. fig. 3.

CIOCALYPTA, Bowerbank.

Skeleton composed of numerous closed columns, each consisting of a central axis of compact, irregularly elongated reticulated structure, from the surface of which radiate, at about right angles, numerous short simple cylindrical pedicels, or stout fasciculi of closely packed spicula; the distal ends of each pedicel separating and radiating in numerous curved lines, which spread over the inner surface of the dermal membrane, separating and sustaining it at all parts, at a considerable distance from the central axis of the skeleton.

This genus is allied by its structural peculiarities, to a certain extent, to *Dictyocylindrus*, Bowerbank, *Hyalonema*, Gray, and *Alcyoncellum*, Quoy et Gaimard. The central axial column of the skeleton is composed of elongated stout reticulations of siliceous spicula, closely resembling the corresponding tissues of the axial column of a *Dictyocylindrus*; but the space between the surface of the column and the inner surface of the dermis is not filled, as in that genus, by the usual interstitial structures of the sponge, it is completely and widely separated from the dermis in a manner very similar to that of the structure of the greatly elongated cloacal appendage of *Hyalonema mirabilis* as it appears in its present condition in the most perfect specimens in the British Museum and in the collection of Dr. GRAY. There is this difference between the structures of the two genera. The coriaceous dermis surrounding the beautiful spiral axial column of *Hyalonema* is very thick, and is abundantly furnished with projecting oscula; and it does not present any indications of lateral pedicels, either on its inner surface or on the surface of the axial column, while these organs are abundant in *C. penicillus*, and its dermis also is comparatively thin and delicately reticulated.

The dermal portion of the sponge in *C. penicillus*, and the reticulated tissues on its inner surface, closely resemble the corresponding tissues in *Alcyoncellum* in their struc-

ture. The pores, in number, size, and mode of distribution, are very similar to those of *Polymastia robusta*, Bowerbank; but the stratum of these reticulated skeleton-structures is not so thick in proportion, and in *Alcyoncellum* and *Polymastia* there is no central axial column. I could not detect interstitial membranes in any part of the space intervening between the axial column and the dermis in *C. penicillus*; but the skeleton-column is permeated by numerous interstitial canals.

The structure of the short pedicels passing from the axial column to the inner surface of the dermis is different from that of the axis; the spicula composing them are parallel to each other, and they are firmly packed together. The bases of the pedicels arise from the surface and from within the substance of the central column, with which they appear to have no further connexion than that which is necessary to secure them firmly in their respective positions. Their apices present a very beautiful appearance, spreading out towards the inner surface of the dermis in curves diverging at angles of about 45 degrees in every direction over it,—which, when viewed with a microscopic power of about 100 linear, resembles an elaborate and beautifully groined roof of a Gothic crypt. Plate LXXIII. figs. 4 & 5.

Tethea, Lamarck.

The following are the generic characters given by Lamarck, in his 'Anim. sans Vert.' 2nd edit. ii. 384:—

"Téthie (*Tethea*).

"Polypier tubéreux, subglobuleux, très fibreux intérieurement; à fibres subfasciculées, divergentes ou rayonnantes de l'intérieur à la circonférence et agglutinées entre elles par un peu de pulpe; à cellules dans un encroûtement cortical quelquefois caduc. Les oscules rarement perceptibles."

Dr. Johnston's version of the generic characters differs slightly from Lamarck's. It is as follows:—

"Sponge tuberous, suborbicular, solid and compact, invested with a distinct rind or skin, the interior sarcoid loaded with crystalline spicula collected into bundles and radiating from a more compact nucleus to the circumference. Marine."

It is much easier to find faults in the generic characters of both the authors quoted, than it is to improve them. The extreme simplicity of the structural characters of *Tethea* is a strong temptation to endeavour to multiply them; but in doing so, Dr. Johnston has introduced two—the structure of the dermal portion of the sponges, and the tuberous nature of its surface—which are not common to all the known species. If we consider the word "tuberous" in the usual English acceptation of the word, as a body "full of knobs or swellings," then very few or perhaps none of the species of *Tethea* would, in their natural condition, exhibit this character; but all of them would be in a greater or less degree subglobular. Dr. Johnston's description of *Tethea* was founded on the structure of *T. Lyncurium* only; and in this species the "thick rind" is

very distinctly to be seen, but in other species this structure is totally wanting. It therefore ceases to be of value as a generic character, and becomes a specific one only. Under these circumstances I propose the following modification of the previously published generic characters:—

Sponge massive, suborbicular. Skeleton consisting of fasciculi of spicula. Fasciculi radiating from a basal or excentrical point to the surface. Intermarginal cavities unsymmetrical, confluent. Propagation by internal or external gemmulation.

This genus affords us one of the few instances in which we may avail ourselves of external form as a generic character; but even in *Tethea* we approach exceptions to the rule in the depressed form of *T. Collingsii*, Bowerbank, MS., as exhibited in the only perfect specimen of that species which I have seen, and in the still more depressed form of *T. spinularia*, Bowerbank, MS.

Although the skeleton-structures in the species of this genus differ to an exceedingly slight extent, the subsidiary spicula vary exceedingly in the different species. In some, ternate spicula are numerous, and in others they are entirely absent; and stellate forms of spicula occur in many varieties of form.

The sponges of this genus appear to be highly organized. Audouin and Milne-Edwards saw the oscula open and the excurrent streams in action, and I have seen the same myself in a specimen of *T. Lyncurium*. My friend Mr. George Clifton, of Freemantle, Western Australia, in a letter dated 25th January, 1861, writes, "I have sent you several fine specimens of *Tethea*. When these animals are first taken out of the water they are of a brilliant orange-colour, and commence squirting water from the oscula situated on the centre of the upper surface; they also contract considerably, but on being replaced in their native element they regain their natural size and reabsorb water."

The mode of propagation varies in different species. In *T. cranium* and *T. similli-mus*, Bowerbank, MS., it is by internal gemmulation, in *T. Lyncurium* by external gemmulation; and in some other species the mode is not apparent. Plate LXXIII. fig. 6, and Part II. Plate XXIX. fig. 12.

Halicnemia, Bowerbank.

Skeleton formed of a single superior stratum of spicula radiating from the centre to the circumference of the sponge at about its middle, and of an inferior stratum of spicula distributed without order.

The nearest alliance to this genus appears to be *Tethea*, in which the skeleton is formed of numerous fasciculi of spicula radiating from the centre to all parts of a spherical or elliptical mass; while in *Halicnemia* the radiating fasciculi are confined to a common plane, beneath which there is a second stratum of spicula, which fills the space beneath the radial stratum and the lower surface of the sponge, but without being disposed in order, and the spicula of the inferior stratum differ materially in form and proportions from those of the superior one.

In the only two specimens of this genus that I have seen, there is a small pebble imbedded in the centre of each sponge, from the surface of which the basal fasciculi of the radial series emanate; but although this appears to be the established habit of this species, it is advisable not to consider it as a generic character, although it may eventually prove to be that the pebble is as much a portion of the skeleton of the animal as the grains of extraneous matter which are taken up by and become imbedded in the keratose fibres of the genus *Dysidea*. Plate LXXIV. figs. 4 & 5.

DICTYOCYLINDRUS, Bowerbank.

Skeleton without fibre, composed of a loosely compacted columnar axis of spicula, disposed principally in the direction of the line of the axial column, from which a peripheral system of long single or fasciculated defensive spicula radiate at right angles to the axial column.

Halichondria hispida, Johnston, and *Spongia stuposa*, var. *damicornis*, Montagu, are excellent types of the peculiar mode of arrangement of the spicula which characterizes this genus. The skeleton consists of a central column of large elongate spicula, disposed principally in the line of the axis of the sponge and at a slight angle to it, approaching in form an irregular cylinder of network of elongated meshes, rarely exhibiting an appearance of horny fibre, but formed for the most part of spicula cemented together near their terminations. Towards the base of the sponge the horny substance surrounding the spicula is sometimes so thick as to simulate a proper horny fibre; but if it be carefully traced, it will always be found to be dependent on the spicula: where their course is abruptly terminated the horny structure also terminates, whereas in true horny fibrous structures which contain spicula the course of the fibre is continuous and uniform whether the spicula be present or deficient, and in the newly produced fibre the latter is generally the case.

The structure of the skeleton in this genus differs from that of *Halichondria oculata*, Johnston, or *Chalina oculata*, Bowerbank, in the regularly elongate disposition of the spicula of the skeleton; and the spicula are necessarily very much larger and longer than those included in the close fibrous network of *H. oculata*; and it is still further removed from the horny fibrous structure of *Halichondria cervicornis*, Johnston, Hist. Brit. Sponges, pl. 4. The axial column of this genus differs strikingly from that of the strong closely packed axis of *Ecionemia*; and the peripheral system of spicula are never furnished with ternate connecting spicula. All the species of this genus I have hitherto seen are more or less ramous in form. Part II. Plate XXIX. fig. 11; and Plate LXXIII fig. 7.

PHAKELLIA, Bowerbank.

Skeleton composed of a multitude of primary cylindrical axes, radiating from a common base and ramifying continuously, from which emanate at about right angles to the axes a secondary series of ramuli, which ramify continuously as they progress towards the surface, but never appear to anastomose.

I know of no other species, either British or foreign, that possesses the peculiar conformation that distinguishes the sponge that is the type of this genus. The primary cylindrical axes very closely resemble those of *Dictyocylindrus*; but in that genus the spicula radiating from the axes are separate and distinct, each having its proximal end based on the primary cylinders of the skeleton, and its distal one reaching nearly to, or passing through, the dermal membrane of the sponge; or if they be fasciculated, the fasciculi are simply plumose, and in no case with which I am acquainted at all ramulose. In *Phakellia* the secondary skeleton is formed of distinct slender branches, each composed of numerous spicula ramifying continuously, and each ramulus increases in size and the number of its spicula as it approaches the surface of the sponge. Single spicula are frequently projected from the ramuli in an ascending direction at an angle of a few degrees, and at their distal terminations at the surface of the sponge; the whole of the terminal spicula radiate more or less at angles from their axial line, and, passing through the dermal membrane, form the external defences of the sponge. Although constantly ramifying and freely intermingling, I have never detected them anastomosing. The term *Phakellia* is applicable to both the primary and secondary ramifications of the skeleton. The type of this genus is *Halichondria ventilabrum*, Johnston. I have not yet met with an exotic species of the genus. Plate LXXIV. fig. 1.

The genera *Microciona*, *Hymeraphia*, and *Hymedesmia* form a group essentially different in structural character from the other genera of the Spongiadæ; but they are closely allied to each other by the peculiar characters of their basal membranes, in conjunction with the other parts of the skeleton. From the nature of their structures, the species generally assume a thin coating-form and are often very minute.

In most of the genera of Spongiadæ the basal membrane of the sponge ceases to be of marked importance after the earliest stages of its development, but in these genera it continues throughout the whole existence of the sponge to form an important part of its skeleton-structure. It is a common base whence spring the whole of the other component parts of the skeleton; and its importance is further indicated by its also being in some species the common base of the internal as well as the external defensive spicula of the sponges in which those organs occur.

Microciona, Bowerbank.

Skeleton a common basal membrane, whence spring at or about right angles to its plane numerous separate columns of spicula intermixed with keratode, furnished externally with spicula which radiate from the columns at various angles towards the dermal surface of the sponge.

The skeleton of the type of this genus, *M. atrosanguinea*, is different from that of any other genus of sponges that I have hitherto seen. It consists of numerous nearly equidistant, short, straight separate columns of spicula and keratode, from all parts of

the sides of which spring stout, long, curved, fusiformi-attenuato-subspinulate spicula, the convex side of each spiculum being outward; and each column terminates with five or six of these spicula disposed in the same manner and at the same angle to the axial line of the column, that is, from about twenty to forty-five degrees. The proportions of the skeleton-columns vary in different species. In *M. atrosanguinea* they are short, stout, and exceedingly well defined. In *M. ambigua* they are short and indistinctly produced, and in *M. carnosa* they are long, slender, flexuous, and frequently branched; but however they may vary in their proportions in different species, their normal character, both as regards structure and position in the sponge, is always preserved. Plate LXXIV. fig. 2, and Part II. Plate XXX. figs. 1 & 2.

Genus Hymeraphia, Bowerbank.

Skeleton a single basal membrane, whence spring numerous large separate spicula, which pass through the entire thickness of the sarcodous stratum, to or beyond the dermal surface of the sponge.

This genus is nearly allied to *Microciona*, but is more simple in its structure, as, in place of the columns of the skeleton compounded of keratode and spicula cemented together and emanating from a common basal membrane as in the latter genus, we find single spicula only, devoid of keratode and based on a common membrane, whence they pass through the entire substance of the sponge; and in all the species at present known they penetrate the dermal membrane and project beyond its surface to a considerable extent, thus combining the two offices of skeleton and external defensive spicula. These organs are therefore, as compared with the skeleton-spicula of other members of the Spongiadæ, and to the entire mass of the sponges to which they belong, of exceedingly robust proportions, their length being frequently twice that of the entire thickness of the sponge.

These peculiarities of structure indicate a common habit of extreme thinness in the species; and such is in reality the condition of those with which we are acquainted. Part II. Plate XXX. fig. 3.

Hymedesmia, Bowerbank.

Skeleton a common basal membrane sustaining a thin stratum of disjoined fasciculi of spicula.

The species on which this genus is founded very closely resembles in habit and general appearance those of the genera *Microciona* and *Hymeraphia*, and in regard to the special offices of the basal membrane it assimilates with them completely. But it differs from them inasmuch as the spicular portions of the skeleton do not emanate immediately from the basal membrane, but are recumbent on it in the form of disjoined fasciculi of spicula. But although different from them in this important respect, the close alliance with them is indicated by the common habit of the possession by the basal membrane of the whole, or nearly so, of the defensive spicula of the sponge, indicating the common property of extreme thinness of structure which exists in these genera.

The free condition of the fasciculi of the skeleton connects this genus in some degree with the Halichondroid genera of sponges, but there are none of the species of those genera in which the fasciculi of the skeleton are separate from each other. The nearest allied genus in that direction appears to be *Hymeniacidon*. Plate LXXIV. fig. 3, and Part II. Plate XXXI. fig. 8.

Suborder II. Spiculo-membranous skeletons. Composed of interstitial membranes having the skeleton-spicula irregularly dispersed on their surfaces.

The prominent character of this Order is, that the spicula of the sponges composing it do not assume either the radiate, fasciculate, or reticulate structural arrangement, the distribution of the spicula on the interstitial membranes being without any approximation to order.

HYMENIACIDON, Bowerbank.

Skeleton without fibre; spicula without order, imbedded in irregularly disposed membranous structure.

In *Hymeniacidon* the spicula are subordinate to the membranous structure, they follow its course and are imbedded without order on its surface. The contrary is the case in *Halichondria*. The network of spicula in that genus, although irregular, is decidedly the predominant structure, and the membranous tissues are secondary to it and exist only as interstitial organs. The larger and stouter of the spicula in *Hymeniacidon*, although dispersed amid the slender ones, may be considered as the representatives of the skeleton-spicula, while the slender ones are truly those of the membranes.

In some species the interstitial tissues are constructed diffusely, as in *H. caruncula*, while in other species, as in *H. subereum* (*Halichondria suberea*, Johnston) and a few other closely allied species, they are more than usually compact, so that in the dried state the texture of these sponges is very like that of fine hard cork. From this peculiarity of their appearance in the dried condition, and the exceeding compactness of their structure, I was formerly inclined to believe them to be generically different from the great mass of the species of *Hymeniacidon*, and I accordingly inserted them in the list of British sponges, published in the Report of the Dredging Committee in the Reports of the British Association for 1860, under the titles of *Halina suberea*, *H. ficus*, &c.; but a closer examination of their internal structure has convinced me that their only real difference from the other species of *Hymeniacidon* is in their greater compactness of skeleton-structure, and I have accordingly removed those species to the genus *Hymeniacidon*.

In the greater number of the species of this genus the tension spicula are of the same form as those of the skeleton, and are only to be distinguished from them by their greater degree of tenuity; but in a few of the known species they are different both in size and form.

The mode of propagation in all the species in which I have found the reproductive organs appears to be by internal gemmulation. In *H. carnosum* and several other species

of the genus the gemmules are simple, spherical, aspiculous membranous vesicles, filled with round or oval vesicular molecules. The genus *Halisarca*, Dujardin, was supposed by both that author and Dr. JOHNSTON to be entirely destitute of spicula; but I have, since the publication of the 'History of the British Sponges,' found them in *H. Dujardinii* in abundance. They are so minute and so completely obscured by the surrounding sarcode, that they can rarely be detected in either the living or the dead specimens when examined in water; but if a portion of the sponge be dried on a slip of glass and covered with Canada balsam, they may be detected by transmitted light and a power of 400 linear in considerable numbers, dispersed on the interstitial membranes of the sponge. This genus will therefore merge in that of *Hymeniacidon*, with which it agrees in every structural peculiarity. Plate LXXIV. fig. 6.

Suborder III. Spiculo-reticulate skeletons. Skeletons continuously reticulate in structure, but not fibrous.

Halichondria.
Hyalonema.
Isodictya.
Spongilla.

The sponges of this suborder vary in the different genera to a great extent in the mode of the construction of the skeleton, but in all cases the spicula are the dominant material; their terminations overlap each other, and they are cemented together by keratode. The reticulations thus formed sometimes consist of a single series of spicula, at other times they are very numerous and are crowded together in the manner of elongated fasciculi.

The genera *Halichondria* and *Isodictya* are exceedingly rich in species; but the inconvenience attending their discrimination, arising from their number, may be remedied to a great extent hereafter by subdivisions of each genus, based on the characteristic forms of the spicula of their respective skeletons. The structural distinction between *Halichondria* and *Isodictya* is so well marked as to render the recognition of each comparatively certain and easy. The skeletons of the species of the latter genus, generally speaking, are very much more slight and fragile than those of the former one; and the same rule obtains to a great extent as regards the comparative size of their spicula, and in many species of *Isodictya* they are very minute. *Hyalonema* and *Spongilla* are readily to be distinguished by the peculiarities of their structure and localities.

The genus *Halichondria* as constituted by Dr. FLEMING in his 'History of British Animals,' and adopted by Dr. JOHNSTON in his 'History of British Sponges,' contains species which differ exceedingly in their mode of organization. Thus, if we take *H. panicea* of JOHNSTON, which is undoubtedly the "sponge-like crumb of bread" of ELLIS and the older authors, and therefore the proper type of the genus, we find the skeleton destitute of fibre, but composed of an irregular network of spicula cemented together at their apices by keratode. If we examine the well-known branching sponge

so common on all our coasts, *Halichondria oculata* of the same author, we find an abundance of keratose fibre containing spicula deeply imbedded in its substance, but not necessarily uniting at their apices; and the network of the skeleton is not irregular as in the first instance, but on the contrary is more or less symmetrically disposed in all parts of the sponge. If we take *Halichondria suberea* of the same authors, we find neither network of spicula nor a keratose fibrous structure, but apparently an amorphous sarcoid mass containing spicula and membranes, on which the former are dispersed without any order or connexion. As we extend our researches among the other British species of FLEMING'S genus *Halichondria*, other striking and permanent variations in the arrangement of their skeleton-tissues present themselves. Their great differences in structure therefore afford ample grounds for the division of the species comprehended under *Halichondria* as constituted by FLEMING into a series of genera having each for its base a separate type of organization; and as the variations in structural character, some of which are mentioned above, are both numerous and strikingly characteristic, I propose to limit the genus *Halichondria* to those species only which agree in their organization with *H. panicea* of JOHNSTON, and to distribute the remaining species in other genera, the distinctive characters being in all cases based primarily on the different modes of the organization of the skeleton of the animal, and when necessary taking in aid such other organic characters as may be found available for the purpose of accurate discrimination. I therefore propose to limit the genus *Halichondria* to those sponges only that exhibit the following characters.

HALICHONDRIA, Fleming.

Skeleton without fibre, composed of an irregular polyserial network of spicula cemented together by keratode.

Type, *Halichondria panicea*, Johnston.

The anatomical structure of the group included under this genus is distinct and unmistakeable. There is no fibre whatever, the skeleton being formed of spicula collected into bundles of a greater or less number, cemented together by keratode, which substance, however, does not extend beyond the space occupied by the respective bundles; and when parts of the reticulated skeleton are formed of single series of spicula only, they are simply cemented together at their points, and the reticulated skeleton thus formed has no definite arrangement. Plate LXXIV. fig. 7, and Part II. Plate XXXII. figs. 1 & 5.

HYALONEMA, *Gray*.

Dr. GRAY has characterized this genus in his descriptions of genera of Axiform Zoophytes, or Barked Corals, as "coral subcylindrical, rather attenuated, and immersed in a fixed sponge. Axis in the form of numerous elongated, slender, filiform, siliceous fibres, extending from end to end of the coral, and slightly twisted together like a rope. Bark fleshy, granular, strengthened with short cylindrical spicula. Polypiferous cells scattered, rather produced, wart-like, with a flat radiated tip." (Proceedings of the

Zoological Society of London for 1857, page 279.) This description applies only to the singular cloacal appendages to the sponge from amidst which it springs, the structure of the body of the animal being evidently considered by the author as an extraneous mass. The basal sponge is undoubtedly a portion of the animal to which the part described by Dr. Gray belongs, the spicula of the elongated cloacal portion being also abundant in the basal mass of sponge; and the basal mass of the specimen described by Dr. Gray is identical in its structural character with that of the specimen of *Hyalonema mirabilis* in the Bristol Museum. It becomes necessary therefore to remodel the generic characters so as to embrace the leading distinctive structures of the skeleton of the animal; and I propose the following form of description:—

Skeleton an indefinite network of siliceous spicula, composed of separated elongated fasciculi reposing on continuous membranes, having the middle of the sponge perforated vertically by an extended spiral fasciculus of single, elongated and very large spicula, forming the axial skeleton of a columnar cloacal system.

The construction of the skeleton of the mass of the sponge is intermediate between that of *Halichondria panicea* and *Hymeniacidon caruncula*, the respective types of those genera. The network of fasciculated spicula appears never to be definite and continuous as in the former, nor are the skeleton-spicula in a dispersed condition on the continuous membranes as in the latter, but are gathered into elongated fasciculi which cross each other in the same plane in every imaginable direction, but without ever appearing to anastomose. The fasciculi vary exceedingly in the number of spicula of which their diameter is formed, sometimes consisting of two or three spicula only, and at other times of more than it is possible to count. They often divide, the branches passing in different directions, but they never reunite or anastomose with other fasciculi. A portion of this network of spicula is represented by figure 3, Plate XXXI. Part II. The columnar axis of the cloacal system consists of one large spiral fasciculus of spicula, each of which extends from the base or very near that part of the sponge, to near or quite to the apex of the column, the direction of the spiral being from right to left.

There is a close approximate alliance to this form of the cloacal appendage of *Hyalonema* in the corresponding organs of the British genus *Ciocalypta*, Bowerbank, MS.

Isodictya, Bowerbank.

Spongia, Montagu.
Halichondria, Fleming.
Halichondria, Johnston.

Skeleton without fibre; composed of a symmetrical network of spicula; the primary lines of the skeleton passing from the base or centre to the surface, and the secondary lines disposed at about right angles to the primary ones. Propagation by internal, membranaceous, aspiculous gemmules.

This genus, in the structure and arrangement of its skeleton, is intermediate between

Halichondria and *Chalina*, as defined in the present work. Like the former, the spicula of the network composing the skeleton are merely cemented together, not enclosed within a regular horny fibre; but the disposition of the network is not entirely irregular, but like that of the latter genus, more or less composed of a primary series of lines radiating from the axis or base of the sponge, and of secondary series connecting the primary ones at about right angles to them—in fact simulating very closely the arrangement of the skeleton of *Chalina oculata*, but without the keratose fibre surrounding the spicula of the skeleton in that sponge.

In some of the species of this genus the symmetrical arrangement of the lines of the skeleton is distinct only near the surface of the sponge, while in the more deeply seated parts the irregular character of a *Halichondria* is simulated. In determining the species of this genus, the sponge requires to be carefully examined by sections at right angles to the surface, where the distinctive character rarely fails to be readily detected. On the contrary, in *Halichondria panicea*, the type of that genus, I have never succeeded in finding such a linear arrangement of the skeleton as marks that of *Isodictya*. In a hasty examination a single linear series of spicula will therefore often prove an excellent guide to the discrimination of this genus.

In most of the species with which I am acquainted there is a generally prevailing character of fragility—the primary lines being composed of very few spicula, while the secondary ones are most frequently unispicular. Most of the species are thin-coating or encrusting sponges, and rarely appear to rise in tuberous masses, as the numerous species of *Halichondria* are in the habit of doing.

Isodictya infundibuliformis is perhaps the most perfect type of the genus, as in it we have the primary and secondary lines of the skeleton distinctly separated by the difference in the form of their spicula. In some species of the genus, as in *I. simulo*, the cementing keratode of the skeleton is so abundant in some parts as to cause it to simulate very closely the structure of a *Chalina*; but the irregularity and compressed form of this pseudo-fibre is readily to be distinguished from true keratose fibre by a careful observer. In other species, as in *I. mammeata*, the sarcode surrounding the skeleton is so abundant as to cause it to simulate a delicate form of *Chalina*; but on immersion in Canada balsam the fibre-like form disappears, the sarcode contracting into a mere granulated coating, and the skeleton assumes the normal appearance of *Isodictya*. Plate LXXIV. fig. 8.

SPONGILLA, Linnæus, Lamarck, and Johnston.

Halichondria, Fleming.

The structural peculiarities of the skeleton of *Spongilla* are the same as those of *Isodictya*; and if there had not existed a striking distinctive difference in their reproductive organs, the two genera must have been united. Under these circumstances I propose the following as the characters of the genus *Spongilla*.

Skeleton without fibre, composed of a symmetrical network of spicula; the primary

lines of the skeleton passing from the base or centre to the surface, and the secondary lines disposed at about right angles to the primary ones. Reproductive organs ovaries, coriaceous and abundantly spiculous.

All the species are inhabitants of fresh water. The best type of the genus is *Spongilla fluviatilis*, Johnston. As an illustration of the form of the skeleton in this genus, see the figure of that of *Isodictya Normani*, Plate LXXIV. fig. 8.

Suborder IV. Spiculo-fibrous skeletons. Regularly fibrous. Fibres filled with spicula.

Desmacidon.
Raphyrus.

The spiculo-fibrous skeletons differ from the fibro-spicular ones in this respect. In the first the form and proportions of the fibre are dependent on the greater or the less development of spicula, and the keratode serves only as a cementing and coating material. In the latter the keratode is the primary agent in the formation of the fibre, and the spicula the secondary or auxiliary agent only.

DESMACIDON, Bowerbank.

Halichondria, Johnston.

Skeleton fibrous, irregularly reticulated. Fibres composed entirely of spicula arranged in accordance with the axis of the fibre, cemented together and thinly coated with keratode.

The structure of the skeleton-fibre in this genus readily distinguishes it from all others. The form and size of the tissue is entirely dependent on the greater or less quantity of spicula present, the keratode serving only as a cementing and coating material. *Halichondria ægagropila* and *H. fruticosa*, Johnston, are the only two British species of the genus known. Part II. Plate XXVII. fig. 10.

RAPHYRUS, Bowerbank.

Skeleton fibrous, but not horny. Fibre composed of a dense mass of siliceous spicula mixed together without order.

The structure of this genus is singular. The fibre in the only species with which I am acquainted, *Raphyrus Griffithsii*, is comparatively very coarse, frequently attaining the size of a line in diameter near the anastomosing parts, or expanding into a broad plate-like form. The spicula composing it are closely thrown together without any approach to the longitudinal disposition which prevails in the skeleton of *Desmacidon*. The same absence of definite arrangement obtains in the interstitial membranes, which have precisely the mode of structure which characterizes the genus *Hymeniacidon*, which has "spicula without order, imbedded in irregularly disposed membranous structure." Part II. Plate XXVII. fig. 11.

Suborder V. Compound reticulate skeletons, having the primary reticulations fibro-spiculate, and the interstices filled with a secondary spiculo-reticulate skeleton.

Diplodemia.

This genus forms a connecting structural link between the orders Silicea and Keratosa. The structure of the keratose fibre would indicate its place to be in the third suborder of the latter; but the presence of the Halichondroid secondary skeleton in such force, in conjunction with the irregular spiculated structure of the keratose fibrous primary skeleton, has induced me to place it among the Silicea. For more minute information regarding its structural peculiarities, I must refer my readers to the following description of the generic characters of *Diplodemia*.

DIPLODEMIA, Bowerbank.

Skeleton fibrous; fibres keratose, hetero-spiculous; combined with a secondary skeleton of irregular network of spicula; rete unispiculate, rarely bispiculate. Ovaries membranous and spiculous.

The fibres in the skeleton of the only known species in this genus are very remarkable. They are smooth and cylindrical, having an axial line of, generally speaking, single spicula united at their points, running throughout the whole length of the fibre. But when it is of more than ordinary diameter, there are frequently other spicula at intervals imbedded in the fibre, parallel to the axial series. Throughout the whole length of the fibres, at short intervals, there are similar spicula to the axial ones, imbedded at right angles to the axis of the fibre, frequently projecting from the surface for half, or more than half, their length. Some of these projecting spicula originate small lateral branches of the keratose skeleton; but by far the greater portion of them are the connecting points of the keratose fibres and the reticulo-spiculate secondary skeleton, the former being thus completely imbedded amidst the latter.

The structure of the ovaria in this genus is also peculiar to it. The wall is very thin, and appears to consist of a single membrane profusely furnished with spicula which cross each other in every direction, and occasionally appear to assume a somewhat fasciculated arrangement. They are not uniform in shape, some being regularly oval, while others are more or less ovoid.

But one species of this singular genus is known, *D. vesicula*, Bowerbank, MS., from deep water at Shetland. Plate LXXIII. fig. 8, and Part II. Plate XXXIV. fig. 1.

Suborder VI. Solid siliceo-fibrous skeletons. Skeletons reticulate. Fibres composed of concentric layers of solid silex, without a central canal. Reticulations unsymmetrical.

Dactylocalyx, Stutchbury (*Iphiteon*, French Museum).

The structure and mode of growth in this suborder of siliceo-fibrous sponges appear

to be precisely the same as that of the kerato-fibrous sponges of the first suborder of Order III. Keratosa.

Dactylocalyx pumicea, Stutchbury, was described in the Proceedings of the Zoological Society, part ix. 1841, p. 86, October 26, 1841. The author describes it thus: "Sponge fixed, siliceous; incurrent canals uniform in size; excurrent canals large, forming deep sinuosities on the outer surface, radiating from the root to the outer circumference."

The sponge was received by the Bristol Museum from Dr. Cutting of Barbadoes.

The genus *Dactylocalyx* was established by Mr. Stutchbury to designate this fine siliceo-fibrous sponge. Half of the type specimen is in the Museum at Bristol, and the remaining portion in the possession of Dr. J. E. Gray of the British Museum. Although the sponge was designated *Dactylocalyx pumicea*, no generic characters were given. I propose therefore to characterize it as follows:—

Dactylocalyx.

Skeleton siliceo-fibrous. Fibres solid, cylindrical. Reticulations unsymmetrical. Part II. Plate XXXIV. fig. 17.

Suborder VII. Canaliculated siliceo-fibrous skeletons. Skeletons reticulate, symmetrical. Fibres composed of concentric layers of solid silex, with a continuous central canal.

Type, *Farrea occa*, Bowerbank, MS.

I have seen in the organic remains from deep-sea soundings several varieties of fragments of siliceous fibres with simple central canals, having every appearance of being from unknown species of siliceo-fibrous sponges; but the only satisfactory specimen of this genus of sponges is the one at the base of Dr. Arthur Farre's specimen of *Euplectella cucumer*, Owen, described in the Transactions of the Linnean Society of London, vol. xxii. p. 117, plate 21.

The fibres in *Farrea occa* are rather coarse, abundantly tuberculated, and the mode of reticulation is rectangular. Their construction is exactly like those of *Verongia*, the type of the fourth suborder of the third order, Keratosa. Part II. Plate XXVII. fig. 11.

Order III. KERATOSA.

Suborder I. Solid non-spiculate kerato-fibrous skeletons.

The greater number of the sponges of commerce belong to this suborder. How many species are comprised under the designation of "the sponges of commerce" it is very difficult to decide, as we rarely obtain them in their natural condition; but it is certain, from their well-washed skeletons, that their number is considerable, and that at least two distinct genera occur among them. If we assume that the well-known cup-shaped sponge, usually sold as the best Turkey sponge, is the one entitled to the designation of

Spongia officinalis, we shall then have the type of the first suborder of the order Keratosa, distinguished by the above characters. There are two genera belonging to this suborder; the first of these is *Spongia*, Linnæus. Its character is as follows:—

SPONGIA, Linneus.

Skeleton kerato-fibrous. Fibres solid, cylindrical, aspiculous. Rete unsymmetrical.

Type, *Spongia officinalis*, Linnæus.

The number of species of *Spongia* appear to be very considerable; and in all of them the irregular meandering character of the skeleton-fibre readily serves to distinguish them. Plate LXXIV. fig. 9, and Part II. Plate XXVII. fig. 7.

The second genus is founded on the specimen described by SOWERBY in the 'British Miscellany,' p. 87, plate 48, and named by him *Spongia pulchella*. I fortunately have this specimen; and on carefully examining it I find it to possess all the characters of the genus *Spongia*, excepting that the reticulations of the skeleton are very symmetrical; and this is so important a structural difference that I have thought it advisable to constitute it the type of a new genus, the characters of which are as follows:—

SPONGIONELLA, Bowerbank.

Spongia, Sowerby and Johnston.

Skeleton kerato-fibrous. Fibres solid, cylindrical, aspiculous. Rete symmetrical; primary fibres radiating from the base to the apex. Secondary fibres disposed at nearly right angles to the primary ones. Plate LXXIV. fig. 10.

Type, *Spongia pulchella*, Sowerby.

Suborder II. Solid, semispiculate, kerato-fibrous skeletons.

The sponges of this suborder closely resemble in general appearance those of the genus *Spongia*, but they differ very considerably in the structural characters of their skeletons, which consist of a somewhat irregular radiation of primary fibres from the base towards the apex of the sponge, with an unsymmetrical series of secondary fibres emanating from and connecting together the series of primary ones.

The primary fibres are compressed and broad in their form, frequently three or four times the width of the diameter of the surrounding cylindrical secondary ones. But their most striking character is their possessing a considerable number of siliceous spicula, which are irregularly imbedded in their centres; sometimes the series of spicula within the fibre consists of but one or two beside each other, and at other times they are numerous and very irregularly disposed. This central series of spicula appears to exist only in the primary fibres; and I have never been able to detect the slightest indi-

cation of their presence in any of the secondary series. I first described these structural peculiarities in a paper read before the Microscopical Society of London, January 27, 1841; and it is published in vol. i. p. 32, plate 3, of their 'Transactions.'

I have met with numerous instances of the occurrence of this structural arrangement of the skeleton in sponges from Australia and the Mediterranean; but their well-washed condition has left them with but very few capabilities for specific distinction.

I propose to adopt De Blainville's name *Halispongia* to designate this genus, the characters of which are as follows:—

Halispongia, De Blainville.

Skeleton kerato-fibrous. Fibres solid; primary fibres compressed, containing an irregularly disposed series of spicula. Secondary series of fibres unsymmetrical, cylindrical, without spicula. Plate LXXIV. fig. 11.

Suborder III. Solid, entirely spiculate, kerato-fibrous skeletons.

Chalina, Grant.

Skeleton fibrous. Fibres keratose, solid, cylindrical, and interspiculate. Rete symmetrical; primary lines radiating from the basal or axial parts of the sponge to the distal portions. Secondary lines of fibre at about right angles to the primary ones.

The type of this genus, *Halichondria oculata*, Johnston, differs so materially in the structure of its skeleton from that of the type of *Halichondria*, *H. panicea*, Johnston, that it becomes necessary that a distinct genus should be established to receive it and other closely allied British species. The skeleton consists of a solid cylindrical keratose fibre, enclosing a single or compound series of spicula, imbedded at or near its centre, and disposed in lines parallel to its axis, thus forming a structural group intermediate between that of *Halichondria panicea* and *Spongia officinalis*.

In the sponges of this genus the spicula are decidedly subservient to the fibre, which is always cylindrical, and generally very uniform in its diameter throughout the whole of a section made at right angles to its surface; while in the nearly allied genus, *Isodictya*, the reverse is the case, the spicula being the essential basis of the skeleton, while the surrounding keratode, although often abundant, is still only the subservient cementing medium of the skeleton, and never assumes the decidedly cylindrical form of that of the fibre of *Chalina*.

In the Edinburgh Encyclopædia, vol. xviii. p. 844, Dr. Grant proposed the name *Halina* to represent those species which were designated *Halichondria* by Dr. Fleming, and subsequently by Dr. Johnston in his 'History of British Sponges;' but as I have already proposed to restrict the term *Halichondria* to those species which agree in structure with the original type of that genus (*H. panicea*, Johnston), it becomes necessary to select other names to represent the sponges which differ essentially in their structure from that type, and I therefore propose to adopt Dr. Grant's genus *Chalina*, designated

in his 'Tabular View of the Animal Kingdom,' published in 1861, to represent that portion of them which agree in structure with the well-known species described in the 'History of the British Sponges' as *Halichondria oculata*. Part II. Plate XXVII. fig. 8.

Suborder IV. Simple fistulo-kerato-fibrous skeletons.

The type of this suborder is LAMARCK'S *Spongia fistulosa*. The anatomical structure and the general habits of the sponges of this description are so widely different from the true Spongias, that I was induced to establish them as a separate genus, and I accordingly designated and described them as such in the Annals and Magazine of Natural History for December 1845, vol. xvi. p. 400, plate 13. fig. 7. It is unnecessary to enter here into a detailed account of these tissues, as I have described the peculiarities of the structure of the simple fistulo-keratose fibrous skeletons at length in the second part of this paper at p. 755, and figured the tissue in Plate XXVII. fig. 12.

The genus may be characterized as follows:—

VERONGIA, Bowerbank.

Spongia, Lamarck.

Skeleton kerato-fibrous. Fibres cylindrical, continuously fistulose, aspiculous. Rete unsymmetrical.

Suborder V. Compound fistulo-fibrous skeletons.

This suborder is founded on the peculiarities in the structure of the skeleton-fibre of a sponge described by me in the Annals and Magazine of Natural History for December 1845, vol. xvi. p. 405, plate 13. figs. 1 & 2, and also in the second part of this paper, p. 756, and figured in Plate XXVII. figs. 13 & 14.

The genus *Auliskia* is the only one in which compound fistulo-keratose fibres have been found, and it may be thus characterized:—

AULISKIA, Bowerbank.

Skeleton kerato-fibrous. Fibres aspiculous, cylindrical, continuously fistulose; primary fistulæ having minute cæcoid canals radiating from them in every direction. Rete unsymmetrical.

Suborder VI. Regular semi-areno-fibrous skeletons.

The sponges of this suborder have the faculty of appropriating extraneous matter, such as grains of sand, or the spicula of other sponges, which become imbedded in the centre of the cylindrical fibres of their skeletons. The fibres in these cases are regular and cylindrical, and the space between their surfaces and the central line of extraneous matter is frequently one-fourth or one-third of their own diameter. The central axis of extraneous matter usually consists of a series of single grains, but occasionally we find

two or three compressed together. In some genera belonging to this suborder the arenation of the fibres is confined to the primary or radial ones, and the fibres of the secondary system are destitute of extraneous matters. In other genera they occur occasionally in the secondary system as well as in the primary one. In *Stematumenia* the primary fibres are frequently somewhat compressed, and are abundantly arenated. The smaller or secondary series of fibres are usually cylindrical, and most frequently without either grains of sand or spicula. Several of the common Bahama sponges of commerce belong to this suborder; but the best type is the genus *Stematumenia*, described by me in the Annals and Magazine of Natural History for December 1845, vol. xvi. p. 406, plate 14. figs. 1 & 2. The genus may be characterized as follows:—

STEMATUMENIA, Bowerbank.

Skeleton. Primary fibres solid, more or less compressed, containing a central axial line of spicula and grains of extraneous matters. Interstitial structures abundantly fibro-membranous. Part II. Plate XXVII. figs. 3 & 5, and Plate XXVIII. figs. 1 & 2.

Suborder VII. Irregular and entirely areno-fibrous skeletons.

Types, *Dysidea fragilis*, Johnston.
Dysidea Kirkii, Bowerbank.

The peculiarity of this suborder is, that the fibre of the skeleton is a full and complete but elongate aggregation of particles of sand, each separately coated by keratode, forming a series of stout anastomosing fibres, consisting of innumerable extraneous molecules encased by a thin coat of keratode.

In *Dysidea Kirkii*, an Australian species, both the primary and secondary fibres of the skeleton are comparatively large, frequently exceeding half a line in diameter. In our British species, *Dysidea fragilis*, Johnston, the primary fibres are often as abundantly arenated as those of the Australian species, while the secondary ones are only partially filled with extraneous matter, and in this condition they are frequently more or less tubular. Part II. Plate XXVIII. figs. 3, 4 & 5.

The structure and peculiarities of the above-named two species are described in detail in vol. i. p. 63, plate 6 of the Transactions of the Microscopical Society of London.

On the Discrimination of the Species of the Spongiadæ.

One of the reasons why so little progress has been made in our knowledge of the Spongiadæ is, that the generic and specific characters that are visible to the unassisted eye, such as form and colour, are in this class of animals remarkably uncertain and delusive, while all those that are definite and constant require not only a high degree of microscopical power to make them visible, but frequently also a peculiar mode of treatment to render them apparent even beneath the microscope. Thus it is with many

of the finer forms of stellate spicula, which are very characteristic in *Tethea*, *Geodia*, *Spongilla*, and other genera. When we search for them by the dissolution of the tissues in nitric acid, they are so minute that by far the greater part of them, even with the most careful treatment, are washed away; and when the tissues in which they are imbedded are examined in water, they are totally invisible in the sarcode in which they are immersed; and it is only when small portions of such tissues are mounted in Canada balsam that they become distinctly visible *in situ*. The correct classification therefore, as well as the anatomy and physiology, is really a microscopical science; and it is only since we have possessed instruments of high defining and penetrating powers, that we have been properly prepared for the investigation of the structures and the correct determination of the generic and specific characters of these interesting and curiously constructed animals. A careful and patient examination of their component parts is therefore absolutely necessary for the determination of species; and the whole of the structures present should be noted and their peculiarities accurately described.

In the first place we will consider what are the parts of the organization of the Spongiadæ that may be used for the purposes of specific distinction; and secondly, endeavour to form an estimate of their relative values.

The parts of the sponge to be thus employed are as follows:—1. The Spicula. 2. The Oscula. 3. The Pores. 4. The Dermal Membrane. 5. The Skeleton. 6. The Interstitial Membranes. 7. The Intermarginal Cavities. 8. The Interstitial Canals and Cavities. 9. The Cloacal Cavities. 10. The Sarcode. 11. The Ovaria and Gemmules.

1. *The Spicula.*

The spicula in the descriptions of the Spongiadæ are of about the same relative value that the leaves of plants are in botanical descriptions. I have shown in the first part of this paper, published in the Philosophical Transactions for 1858, that they are exceedingly various in form in the different species; and even when of the same shape in two different sponges, as represented in fig. 9 *a* & *b*, Plate XXIII. Phil. Trans. 1858, their relative proportions are frequently so distinctly different as to render them almost as valuable as if they varied from each other in form. Wherever therefore spicula form a component part of the skeleton, they become a leading character in the discrimination of species. But it is not only those of the skeleton that are thus available, as in different sponges they vary in shape and size in each separate organ belonging to the animal; and in some cases we find as many as five or six distinct descriptions of spicula, each of which affords an invariable and excellent character. Thus, in the descriptions of sponges, it is not only the forms and relative proportions of the skeleton-spicula which have to be taken into consideration, but those also of the dermal and interstitial membranes (the external and internal defensive ones), those of the sarcode, and of the ovaries and gemmules. Those of the latter three organs named frequently afford the most determinative characters. Thus in the genus *Spongilla* but one form of spiculum, the acerate, prevails in the skeletons of all the known species; but the minute and

beautiful spicula of the ovaria vary in form and size, in passing from one species to another, in a perfectly unmistakeable manner, so that, if the organs of reproduction be present, which is most frequently the case, the species may be readily recognized from their spicula only. But in other cases, and even in the same genus in the absence of the ovaria, the differences between two nearly allied species are equally well determined by the spicula of the dermal and interstitial membranes. Thus, in our two species of British *Spongilla*, *S. fluviatilis* has no tension spicula different from those of the skeleton, while in *S. lacustris* we find the fusiformi-acerate entirely-spined spiculum, represented in fig. 21, Plate XXIV. Phil. Trans. 1858, in abundance. So likewise in two species of *Tethea*, *T. cranium* from Shetland, and *T. simillima*, Bowerbank, MS., from the Antarctic regions, the only well-determined difference that exists is, that the sarcode of the former is profusely furnished with exceedingly minute sigmoid spicula, while that of the latter is entirely destitute of them. It will therefore be seen that these exceedingly minute organs frequently afford the most valuable and certain means of discriminating species. But although so minute, we must not imagine that it is very difficult to obtain these characteristic evidences; for, as I shall show more at length hereafter, it requires but the dissolution of a small piece of the sponge in hot nitric acid to at once furnish us with a general view of the whole of the spicular contents of the sponge under examination; so that, to one who has become familiarized with the general characteristics of the forms and sizes of the different classes of spicula peculiar to each organ of the sponge, such a preliminary observation at once indicates the nature and especial seat of the principal specific characters of the subject under examination.

In some sponges the relative variation in size of the adult skeleton-spicula is greater than in others; but this variation, although sometimes a substantial character, must not be always assumed to be correct, as in young sponges with simple forms of skeleton it is very difficult to discriminate between the young and only partially developed spicula and the adult ones. Thus in a young specimen of *Spongilla fluviatilis*, I found in the same field of view one spiculum perfectly well proportioned which measured $\frac{1}{324}$th of an inch in length and $\frac{1}{10000}$th of an inch in diameter, another $\frac{1}{341}$st of an inch in length and $\frac{1}{7800}$th of an inch in diameter,—the length and diameter of an average-sized spiculum of the species in a fully developed condition being, length $\frac{1}{75}$th of an inch, and diameter $\frac{1}{2000}$th of an inch.

Abnormal or immature forms must not be mistaken for fully developed and normal ones, as we find in some of the more complicated forms of spicula that the development of form is quite as progressive as that of size, as instanced in figs. 4, 5, 6 & 7, Plate XXIV. Phil. Trans. 1858, which represent the progressive stages of development of the spinulo-recurvo-quaternate form of spiculum, and also in figs. 4, 5, 6, 7 & 8, Plate XXV. Phil. Trans. 1858—where the first four figures represent the progressive development of the dentato-palmate inequianchorate spiculum, and the last an abnormal form, probably arising from arrested development.

2. *The Oscula.*

The oscula frequently afford good specific characters. Their peculiarities are, first, those of position; and secondly, those of form. Thus it should always be noted whether they are dispersed or congregated, whether disposed on the exterior surface or on the parietes of internal cloacæ. In form they are either simple orifices, or they assume a tubular shape to a greater or a less degree, and sometimes they are bounded by a slightly elevated marginal ring. All these characters are subject to a considerable amount of variation, which is sometimes dependent on peculiarities of locality, and at others on age or the amount of their development; but a comparison of several specimens of the same species will generally lead the observer to a correct conclusion regarding their normal characters.

In some species these organs are always more or less open; in others, especially littoral ones, they are entirely closed during exposure to the atmosphere, or while in a state of repose, during which condition they are frequently completely inconspicuous.

3. *The Pores.*

The pores afford but very few available characters. They are either dispersed or congregated, very rarely in the latter state. They are also either conspicuous or inconspicuous: that is, in the former condition their presence, and the areas within which the groups of them are situated, may be readily detected by the aid of a hand-lens; in the latter case they are perfectly undistinguishable without high microscopic power.

4. *The Dermal Membrane.*

The dermal membrane affords many important specific characters. In the greater number of the Spongiadæ it is a simple pellucid membrane, which invests the whole of the mass of the sponge; but in other cases it is of much more complex structure, sometimes furnished abundantly with primitive fibrous tissue, or a network of spicula or kerato-fibrous tissue for its especial support; and in the areas of such network there are frequently tension spicula differing in construction from those of the skeleton, and its interior surface is often supplied with anchorate retentive spicula of various forms. In its sarcodous lining there are occasionally an infinite number of stellate or spherostellate spicula to protect it from the ravages of minute enemies, and its surface is also often penetrated by large or small defensive spicula. Occasionally its external surface is profusely supplied with elongo-stellate defensive spicula. It has also frequently a thick stratum of cellular structure of various colours.

These peculiarities of structure have no generic value. They are essentially specific differences; and it is rarely the case that any two species, even in an extensive genus, are found to agree in the possession of the number, form, or mode of disposition of these peculiarities of the dermal tissues. They form therefore a constant and highly valuable series of characters, and claim the especial attention of the student in either the recognition or description of an unknown species.

5. *The Skeleton.*

Although the material, mode of structure, and arrangement of the skeleton is more especially devoted to the formation of the orders and suborders, it still presents us with a sufficient number of minor peculiarities to render it a source of valuable specific characters. Thus, as I have already shown, in treating of the relative value of the spicula for the distinction of species, the difference in their size affords a good character. The closer or more diffuse mode of their arrangement modifies to a great extent the form and size of the areas in spiculo-reticulated skeletons, and their habitually greater or less number in the thread of the reticulations produces a distinctly different aspect in the skeletons of two otherwise closely allied species. The presence or absence of defensive spicula, the mode of armature, and the forms of the defensive and other auxiliary spicula also afford a very extensive and valuable series of specific characters. In the kerato- and siliceo-fibrous sponges there are peculiarities of a similar description, such as the presence of a reticulo-fibrous sheath, as represented in figs. 9 & 10, Plate XXVIII. Part II., or the possession of spines or tubercles of various forms, as represented in the same Plate, figs. 7 & 8, or of extraordinary modifications for prehension, as in the cidarate siliceo-fibrous skeleton, represented also in the same Plate, fig. 12. These and other similar structural peculiarities afford a series of characters which are usually of a permanent and very striking description.

6. *The Interstitial Membranes.*

The peculiarities of the interstitial membranes consist principally in the shape and proportions of their tension spicula, or of the forms and varieties of structure, and mode of disposition, of the retentive spicula. The latter class of organs especially present a very extensive series of striking characters that are essentially specific. In the genera *Halichondria*, *Isodictya*, *Hymeniacidon*, and others containing numerous species, often very closely resembling each other in all the principal structural characters, they frequently, from the strongly marked peculiarities in their form and proportions, present most valuable and decisive specific characters. Plate XXVII. figs. 1, 2, 3 & 5.

In *Alcyoncellum* and other genera the interstitial membranes are strengthened and supported by layers of primitive fibrous tissue, arranged in parallel lines; and in *Stematumenia* the same fibres abound, but they are not disposed in the same symmetrical manner, and in some sponges cellular structures are present in considerable quantities. These tissues are all more or less valuable as aids in specific distinction.

7. *The Intermarginal Cavities.*

The intermarginal cavities in the greater portion of the Spongiadæ are so indefinite in their form as to render but little service in the distinction of species; but in *Geodia*, *Pachymatisma*, and a few other genera their structure is very much more regular, and their form, proportions, and mode of disposition afford good characters. But although of no extensive essential value themselves, their subsidiary ternate spicula present a

great number of strongly marked specific distinctions, arising not only from their varieties of form and proportion, but also from their relative positions in the dermal crusts of those genera where they most abound; and their modes of disposition and connexion with each other are also very characteristic.

8. *The Interstitial Canals and Cavities.*

These organs themselves present very few characters that are of much service in specific descriptions, but their subsidiary spicula are often very suggestive of the nature and character of the species. Of this description, are the recurvo-ternate spicula in the interstitial cavities immediately beneath the dermal crust of some species of *Geodia*, and just without the dermal membrane of *Tethea cranium*; the remarkable groups of recurvo-quaternate spicula, represented by fig. 10, Plate XXX., Part II.; the trenchant bihamate spicula of *Hymedesmia Johnsoni*, figs. 1 & 2, Plate XXXI.; and many other instances of offensive or defensive spicula, either disposed in groups or singly, in these canals or cavities.

9. *The Cloacal Cavities.*

The cloacal cavities are especially valuable and characteristic in the calcareous sponges. Their position, number, extent, and form—the number and position of their excurrent orifices—the mode in which those orifices are armed and the nature of that armature, or the entire absence of such defences—the internal defensive spicula, their varieties of form, and mode of arrangement,—all these characters are highly effective and valuable as specific descriptions. In other genera of sponges the cloacæ afford striking and very effective distinctions, especially in *Alcyoncellum*, *Polymastia*, *Halyphysema*, and *Hyalonema*. Among the Keratosa also they avail to a considerable extent; but the latter order does not afford us the same wide range of striking characters that exist so abundantly in the cloacæ of the order Calcarea.

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10. *The Sarcode.*

The universal presence and similarity in structure of the sarcode of the Spongiadæ renders the range of its use as a specific character very limited; but the spicula imbedded in its substance so abundantly in many species are so various in form, and so strikingly distinct from each other, as to afford a most valuable series of discriminative characters.

The greater portion of these spicula are more or less stellate in form. They vary in shape to a considerable extent in each group, in consequence of incomplete or complete development, and the number of the radii in the stellate forms is in many cases very uncertain; but although this amount of variation exists in each of the separate forms, there is always a limit to these differences, and a normal character present which renders it by no means difficult to decide to which class they belong. Independently of the peculiar characters of their own form and modes of radiation, their radii are fre-

quently peculiarly and abundantly spinous, and these secondary organs are equally as constant and determinative of specific character as the primary radii. The characters derived from the spines are frequently very minute, and require the application of a high microscopic power to render them available; but they are in many cases so decisively valuable, that they should never be neglected when present. In truth, the modes of spination of these and all other forms of spicula are of considerable value as specific characters, and the shape and direction of the spines are often indicative of the character and purpose of the spiculum on which they are based.

The range of the stellate spicula is very considerable. They are found abundantly and constantly in *Geodia*, *Pachymatisma*, *Tethea*, *Dactylocalyx*, and *Alcyoncellum*, and in some species of *Spongilla*, *Dictyocylindrus*, and other genera.

11. *The Ovaria and Gemmules.*

Where the ovaria exist they afford excellent descriptive characters. Their construction is the same throughout the whole of the known species of *Geodia* and *Pachymatisma*. The varieties in their form, although not always easy of description, are yet readily distinguishable by a practised eye; and the difference in the degree of stoutness of the radiating spicula of which they are constructed, and the consequent fineness or coarseness of the reticulations on their surface, very often afford good discriminative characters.

In *Spongilla*, the varieties in their shape, and the strikingly distinct forms of their component spicula, render them exceedingly efficient for specific descriptions; and without them it would in several instances, among the exotic species, be very difficult to find descriptive characters to separate one species from another.

Excepting in *Diplodemia*, where the structural peculiarities of the ovarium are widely different from the preceding instances, we know very little more of these organs; but there is good reason to believe, from certain forms of spicula detected in the deep-sea soundings, the sources of which are at present unknown, that other marine sponges possess ovaria with which we are at present unacquainted.

The gemmules afford very efficient specific characters in some species of *Tethea*; but in the greater number of Halichondroid genera, although frequently present in abundance, they agree so closely in structure with each other as to render them of very little use as specific characters.

We thus find that we possess eleven distinct varieties of organic specific characters, many of which are exceedingly prolific in materials for descriptive purposes. A long familiarity with them has assured me of their value, and of their constancy in each species. However protean the form and colour may be, the organic structures can always be recognized with certainty, provided the specimen under examination has been dried in the condition in which it has been taken from the sea. To the organic characters may be added the less definite and valuable ones of form and mode of growth, which,

although less to be depended on than the organic ones, are frequently of service in conjunction with them, as leading and suggestive in the first stage of investigation.

A dependence on the specific characters to be derived from form alone inevitably leads to erroneous conclusions. Thus, from trusting too implicitly to it in the descriptions of his species, Dr. JOHNSTON, in his 'History of British Sponges,' has made two species out of one in the case of *Dysidea fragilis*, the thin-coating form of this sponge being also described as *Halichondria areolata*. *Halichondria incrustans* has also been described a second time as *H. saburrata*. An elongated form of *Halichondria ficus* has also been again described as *H. virgultosa*. The type specimen of *Halichondria sevosa*, Johnston, in the British Museum proves to be merely a thin-coating variety of *Halichondria panicea*; and the type specimen of MONTAGU'S *Spongia digitata* in the possession of Professor GRANT, *Halichondria cervicornis*, Johnston, on being microscopically examined, proved not to be a sponge, but an alga. Numerous other instances of error arising from a dependence on form alone as a specific character might be cited; but those I have given above are sufficient to prove the ineligibility of so mutable a character unaccompanied by organic structure.

Nearly the whole of this extensive series of specific characters have hitherto not been applied in the descriptions of the Spongiadæ, excepting in my own manuscripts. This omission has occurred, not from any doubt of their value, but simply because they were unknown to naturalists. It now remains to be proved how they may be rendered available in future descriptions of those animals. I cannot, perhaps, better attain this end than by detailing the order and mode of employing them in the description of species contained in my own Manuscript History of the British Sponges. The following is the order in which these characters have been taken for examination and description:—

1. Form. 2. Mode of Growth. 3. Surface. 4. Oscula. 5. Pores. 6. Dermis, and Dermal Membrane and its Spicula. 7. Skeleton and its Spicula. 8. Connecting Spicula. 9. Defensive Spicula—external, internal. 10. Spicula of the Membranes—tension spicula, retentive spicula. 11. Sarcode and its Spicula. 12. Ovaria and Gemmules, and their Spicula.

Colour.

Habitat.

Condition when examined.

This order of description, or any other that the student may prefer, should always be adhered to, and no part of the specimen under examination that is present, and which affords specific characters, should be omitted in the description; so that, when no mention is made of particular organs or classes of spicula, it may be presumed that they are not present in the sponge in course of description. A certain portion of these characters are always available. Thus the skeleton, incurrent canals or cells, the sarcodous system, the dermal and interstitial membranes, the pores, and the oscula are always present, while the excurrent canals or the cloaca are occasionally absent. The inter-

marginal cavities, if present, are not always distinguishable; and the external and internal defensive organs are, either one or both of them, frequently absent.

Specific characters should always be of a positive nature, such as the presence and form of particular spicula or other organs. It is a great mistake in writing specific descriptions, to make the differences between species to consist of one or two striking essential characters only. Such a practice may answer tolerably well when there are but two or three species of a genus known; but it frequently occurs when new species are found, that they also have the most striking essential characters of the previously known ones equally strongly developed. Much confusion is thus likely to occur from this paucity of description; whereas, if the whole of the essential characters of each species be carefully investigated and accurately recorded when it is first characterized, that description will most probably suffice permanently to distinguish it as a species, however numerous the subsequently discovered members of the genus may be.

Differential characters should never be intermingled with essential ones in characterizing the species. They should be reserved for the amplified history; and here they are of much value, as they lead to the relative consideration of two or more nearly allied species, and frequently assist the student in their discrimination when the essential characters are minute or somewhat obscure.

In the description of species the adjectives long, short, stout, slender, &c., must always be understood as in comparison with the congenerous organs of the species under consideration, and not as in relation to any fixed standard of size.

In the description of a new species it should always be stated whether the characters are given from a dried specimen, or whether from one fresh from the sea, as it frequently happens that many of the *natural* characters become completely obliterated and sometimes reversed by drying; thus the surface smooth in the live state become villous when dried; inconspicuous oscula become conspicuous when contracted and dry, and conspicuous oscula are often destroyed by desiccation; and so on with other characters. It is therefore absolutely necessary that the condition of the specimen should be stated along with its description.

On the Preservation and Examination of the Spongiadæ.

The greater portion of specimens in natural history may be readily examined and their species determined in the field; but this is rarely the case with the Spongiadæ. It becomes necessary therefore to preserve them in such a manner as to effectually retain their natural characters for examination at some future period. Small specimens may be preserved in spirit of wine; but this destroys their colour. If they are not likely to be permanently lodged in the cabinet immediately, it is better that they should be laid on blotting-paper, or a soft cloth, to absorb as much as possible of the water from within them, and then dry them rapidly before a fire, or in a slack oven, without any previous washing in fresh water. By this mode they retain a sufficient amount of moisture and flexibility to allow of their being handled and operated on for examination

with impunity; but the amount of salt thus left within them will in time cause considerable mischief to the specimen. After such specimens have been once thoroughly dried and their examination has been completed, they may be plunged into cold water for a few minutes, and the water then ejected by a rapid centrifugal motion of the arm, and this operation repeated two or three times; the specimen should be again rapidly dried, and it will then keep well in the cabinet and preserve all its characteristic features. It is a bad habit to soak marine specimens for a considerable time in fresh water to extract the salt, as by this mode of proceeding the minute and delicate characters of the object are to a great extent destroyed.

The most advisable mode of proceeding, in the examination of an unknown species, is, first to note the general peculiarities of form and surface as presented to the unassisted eye. After the noting of the external character, the next step should be to cut a slice out of the sponge, to about half an inch or more in depth, at right angles to the surface, taking special care that a due proportion of the dermal membrane is included; this should be placed in a long narrow test-tube, in about an inch deep of nitric acid, in which it should be gently and cautiously boiled over a very small flame until the sponge is entirely dissolved, and then set by until the acid is quite cold and the spicula have subsided to the bottom of the test-tube, so that the greater portion of the acid may be decanted off and its place be supplied with distilled water; and this operation should be repeated three or four times with much care. The spicula thus prepared should be placed in a watch-glass with a little distilled water, and the whole stirred up so that an average sample can be obtained for microscopical examination. By this mode of procedure a general view of the whole of the spicula belonging to the species will be obtained, which will serve as a guide to the subsequent modes of examination.

The boiling in nitric acid should not be continued beyond the time of the piece of sponge falling completely separated to the bottom. If stopped at this period by the addition of a little distilled water, it frequently occurs that undissolved gemmules and portions of the membranes are found, that are very suggestive for the further examinations of the specimen.

The next step should be to take a thin slice from the surface of the sponge, and place it in a cell in a little distilled water, for the purpose of the examination of the structural peculiarities of the dermal membrane. Then take a thin slice from the body of the sponge at right angles to its surface, and mount it in a similar manner for the purpose of ascertaining the nature and peculiarities of its skeleton and other internal organs. These two sections should be carefully examined with the microscope; and if they be not sufficiently characteristic, fresh ones should be mounted. If the specimens thus treated be taken from sponges properly preserved, their tissues will expand and assume very much the appearance of those of the living sponge, and they will as nearly as possible exhibit the natural positions and proportions of the internal organs.

The general characters of these sections should be observed with a half-inch or two-

thirds combination, and again with not less than a quarter-inch object-glass, and the characters of the various tissues in their natural condition be immediately noted. But the whole of their minute organs will not be visible by this mode of examination; and it is therefore necessary to mount the same or similar sections in Canada balsam, by which means the spicula of the sarcode and other minute organs will become completely visible *in situ*; and the specimens thus mounted will serve as permanent records for the cabinet.

The following are a few examples of the mode of specific description that I propose for adoption by naturalists who may investigate the Spongiadæ.

GRANTIA CILIATA, Fleming.

G. ciliata, Johnston.

G. pulverulenta, Johnston.

Sponge elongately oval, rarely globular, slightly pedicelled; surface papillated, hispid. Cloaca central, cylindrical, nearly as long as the sponge; armed internally with spiculated equiangular triradiate spicula; spicular ray attenuated. Mouth of the cloaca armed with a thick ciliary fringe of very long and slender acerate spicula; base of the fringe supported by large, short and stout fusiformi-acerate spicula. Oscula simple, very slightly depressed from the surface of the cloaca, as numerous as the interstitial cells. Pores inconspicuous. Interstitial cells: distal terminations more or less obtusely conical, furnished with a ciliary fringe of slender acerate spicula. Skeleton-spicula equiangular triradiate.

Colour cream-white.

Hab. Coasts of Great Britain; parasitical on fuci; littoral to 8 or 10 fathoms or more. Examined alive.

PACHYMATISMA JOHNSTONIA, Bowerbank.

Halichondria Johnstonia, Trans. Mic. Soc. London, vol. i. p. 63, pl. 6; Johnston's Hist. Brit. Sponges, p. 198.

Sponge massive, sessile; surface smooth, undulating into ridges. Oscula simple, congregated on the elevations. Pores inconspicuous. Dermis crustular, filled with ovaria. Dermal membrane pellucid, abundantly spicular; spicula fusiformi-cylindrical, tuberculated, minute. Intermarginal cavities immersed in the dermal crust, separate, symmetrical, subcylindrical, valvular at proximal end. Connecting spicula attenuato- or cylindro-ternate; radii variable in form and proportions. Skeleton-spicula cylindrical, variable in form and proportions. Spicula of sarcode attenuato-stellate; radii incipiently spinous, rarely fully spinous, or obtuse. Ovaria oval, depressed.

Colour: littoral specimens light to dark slate-grey; deep-sea specimens pink or red. (Captain F. W. L. THOMAS, R.N.)

Hab. Rocks between high and low water mark. Torquay. Gouliot Caves, Sark. Coast of Ireland (J. S. Bowerbank). Orkney Islands, thirty-five fathoms (Captain F. W. L. Thomas, R.N.). Wick, Scotland (C. W. Peach).

Examined in the live state.

Tethea cranium, Lamarck.

Tethea cranium, Johnston.

Sponge ovoid or subspherical, sessile surface even, strongly hispid. Dermal coat thick, abundantly furnished with short, stout, fusiformi-acerate spicula surrounding the large defensive fasciculi at various angles to their axes; also profusely furnished with minute sigmoid bihamate spicula, dispersed irregularly. Dermal membrane thin, pellucid. Oscula and pores inconspicuous. Spicula of the skeleton fusiformi-acerate, large and long. Defensive spicula external, collected in fasciculi; fusiformi-acerate, large and long, fusiformi-porrecto-ternate, and a few fusiformi-recurvo-ternate very long and slender. Sarcode abundantly furnished with minute sigmoid bihamate spicula. Gemmules lenticular, surface smooth, very tough and strong; of two distinct sorts: the first furnished abundantly with slender fusiformi-acerate spicula radiating in fasciculi from the centre to near the surface of the gemmule; the second furnished abundantly with slender fusiformi-acerate, slender unihamate attenuated, and with short slender porrecto-ternate spicula, mixed in fasciculi which cross each other irregularly.

Colour pallid green.

Hab. Island of Fulah (Jameson). Haaf Banks, Shetland (Barlee and Bowerbank).

Examined in the fresh state.

In the specimens of specific descriptions which I have given above, there are fortunately numerous characteristic points by which we may readily separate them from their congeners; but this abundance of characters does not always exist. Thus in *Halichondria caduca* we find the structures so few and simple, as to render their description exceedingly difficult and unsatisfactory.

Halichondria caduca, Bowerbank.

Sponge massive, sessile, surface rugged. Oscula simple, small, dispersed, numerous. Pores inconspicuous. Dermal membrane aspiculous, pellucid, thin. Spicula of skeleton acerate, rarely acute. Interstitial membranes thin, translucent; spicula acerate, slender. Sarcode abundant.

Colour light grey.

Hab. Tenby (Mrs. Brett).

Examined in the dried state.

Fortunately these cases of extreme paucity of characters are very few in number.

Explanation of the Plates.

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Fig. 1. *Grantia.* A longitudinal section of a portion of one side of a specimen of *Grantia ciliata*, exhibiting the structure and mode of disposition of the interstitial cells, ×108 linear: page 1093: see also Part II. Plate XXXIII. fig. 1, for interstitial cells.

Fig. 2. *Leucosolenia botryoides.* Two branches exhibiting the simple fistulose structure of the sponge, ×50 linear: page 1094.

Fig. 3. *Leuconia nivea.* A longitudinal section of one of the mammiform portions, exhibiting one of the great cloacal cavities of the sponge and its internal defensive spicula, ×50 linear: page 1094. 3 *a*, figure of a sponge, natural size.

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Fig. 5. *Geodia Barretti.* A section at right angles to the surface, exhibiting the radial disposition of the fasciculi of the skeleton, and a portion of the dermal crust of the sponge, ×50 linear: page 1098.

Fig. 6. *Pachymatisma Johnstonia.* A section at right angles to the surface, exhibiting the irregularity of the interstitial structures directly beneath the dermal crust, ×50 linear: page 1101.

PLATE LXXIII.

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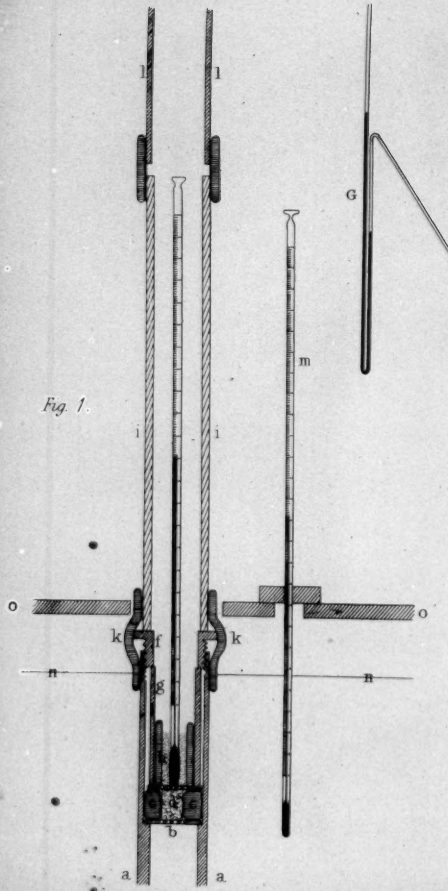


Fig. 1.

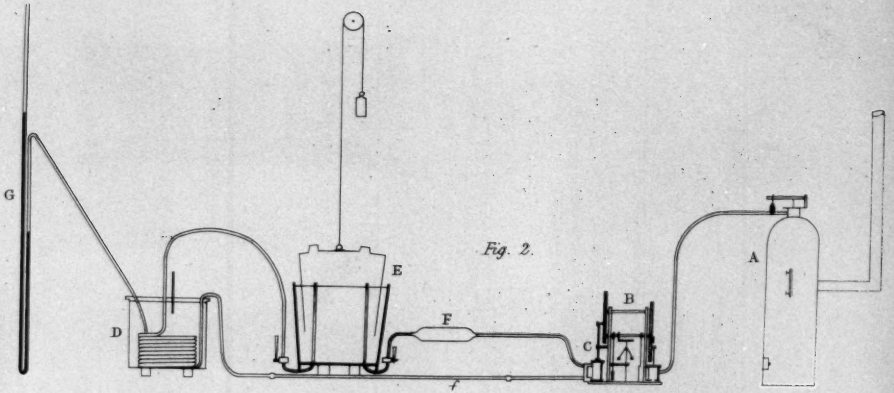


Fig. 2.

Fig. 3.

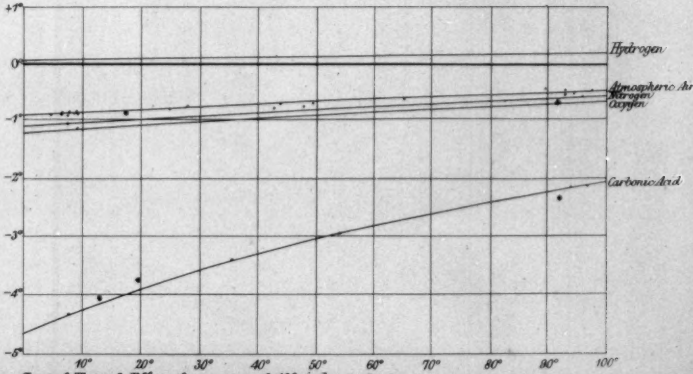
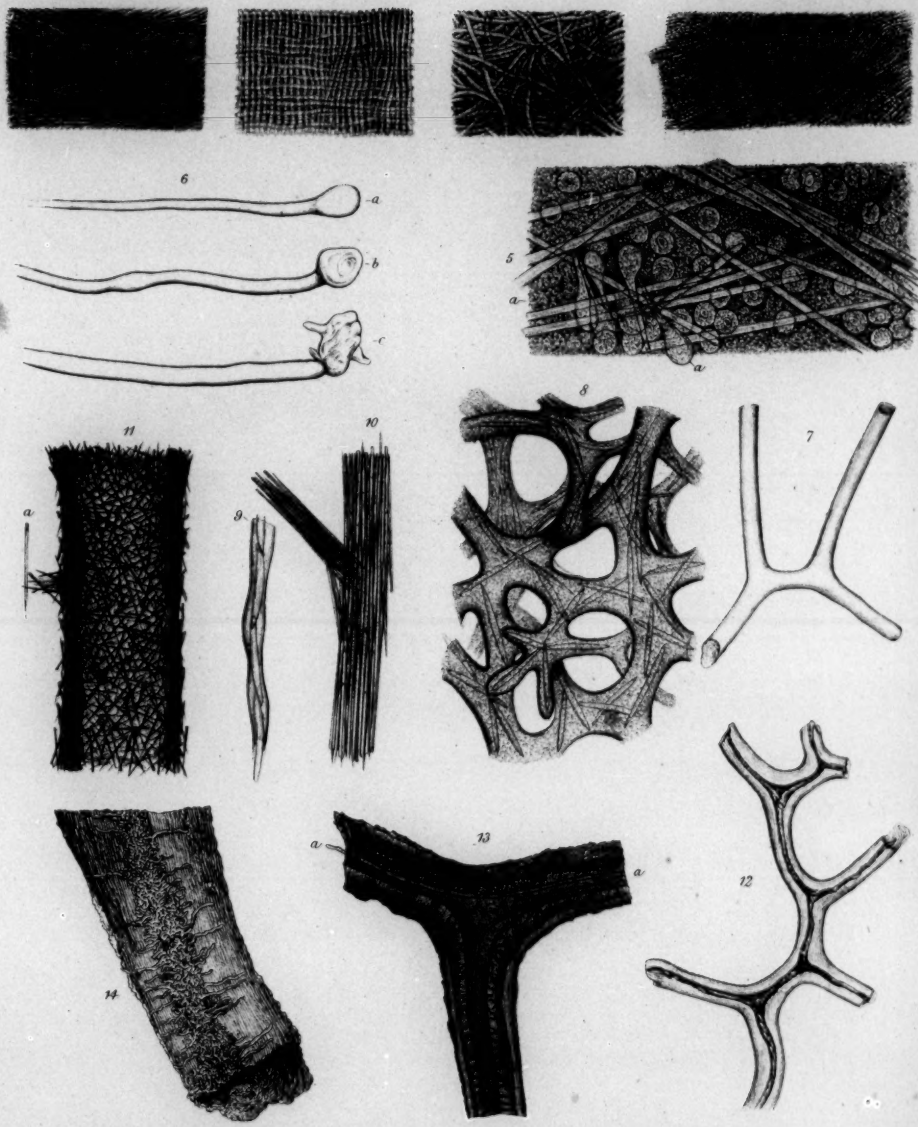


Chart of Thermal Effects for pressure of 100 inches mercury.
The asterisks show the results of the previous paper for Air and Carbonic Acid.



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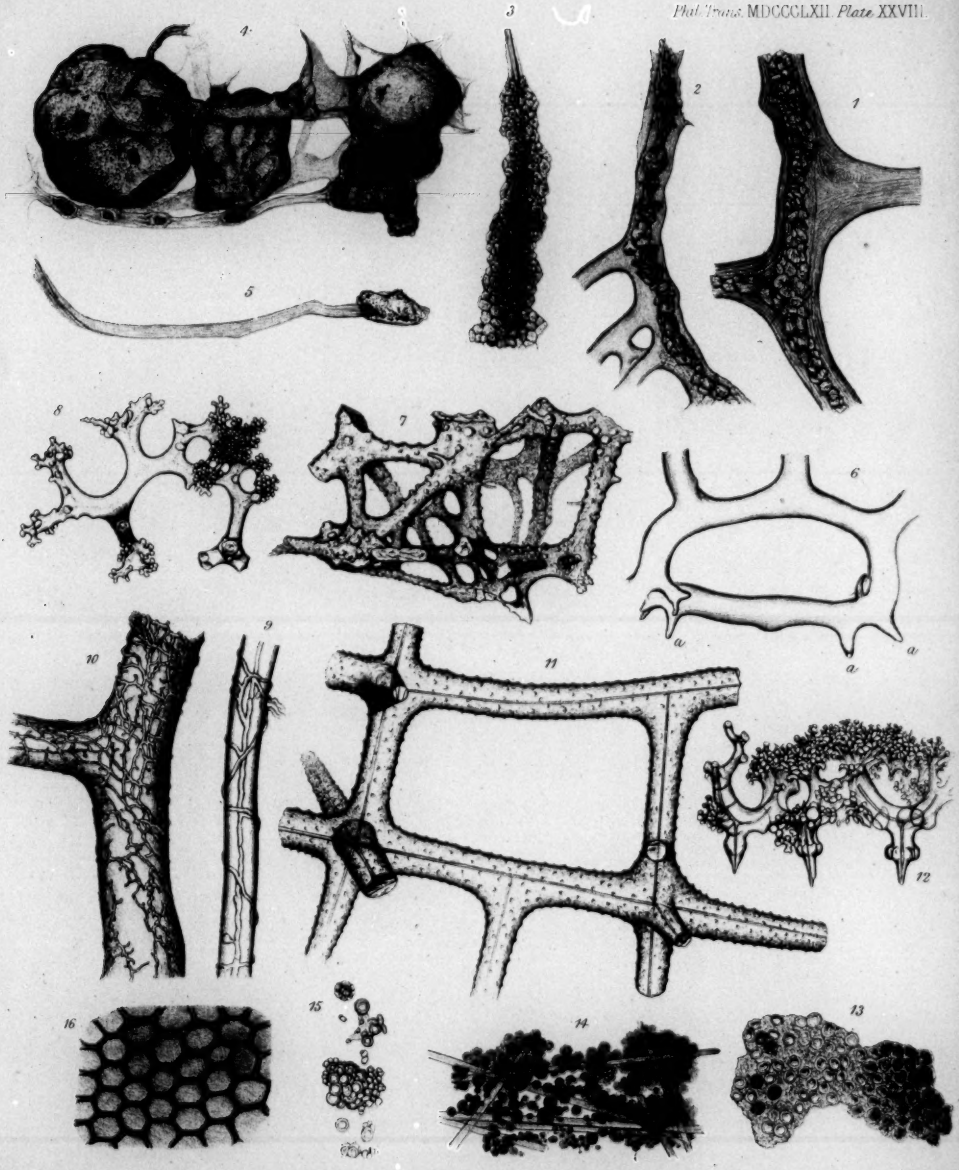

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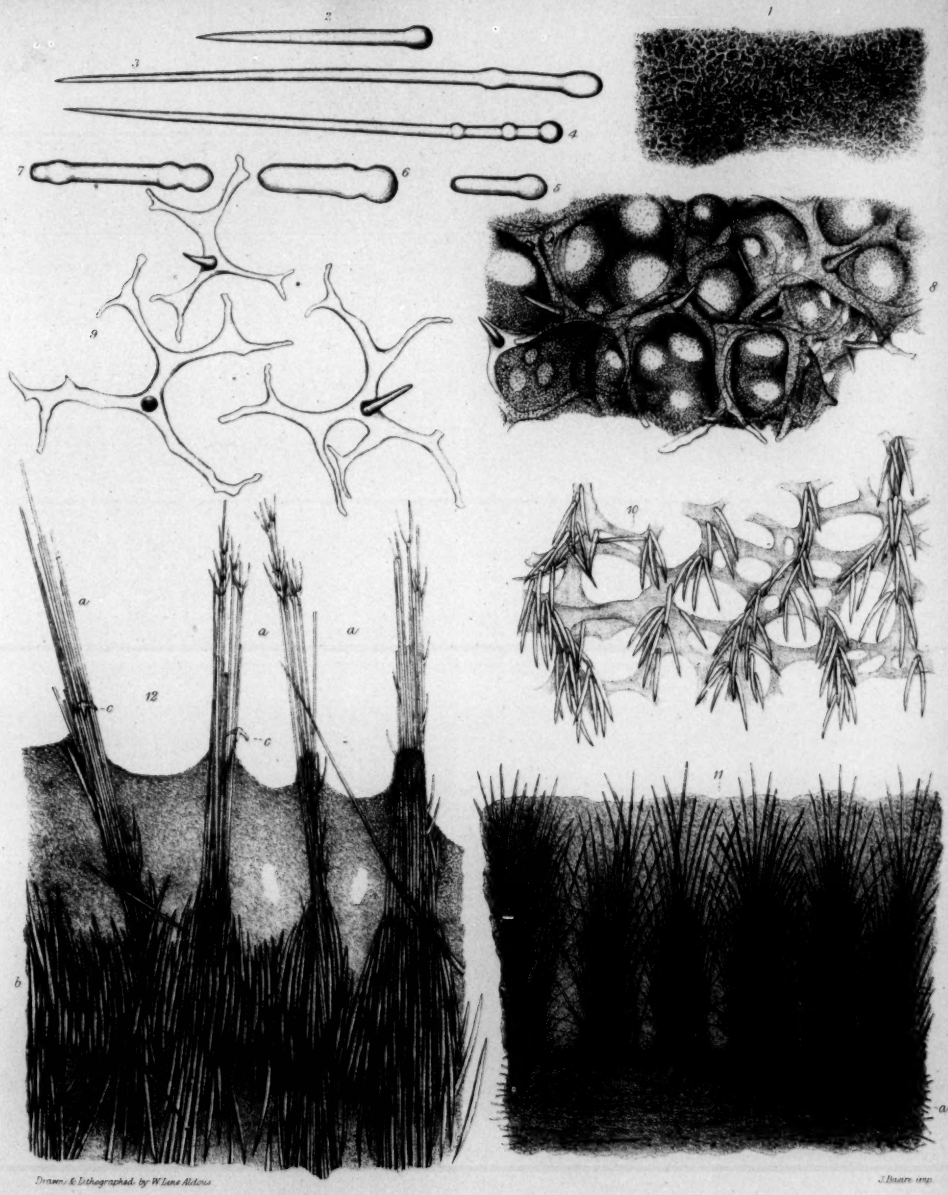

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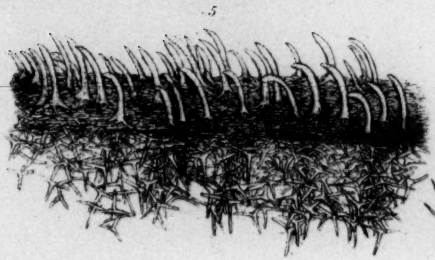

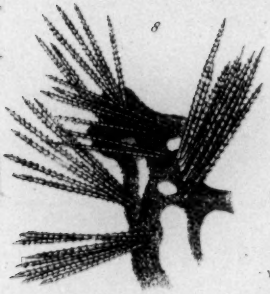

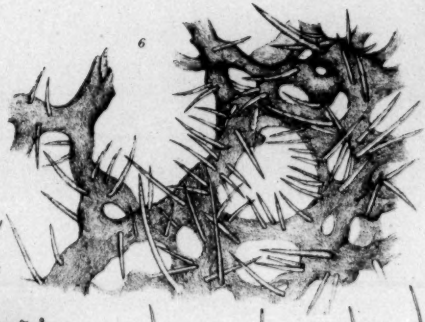

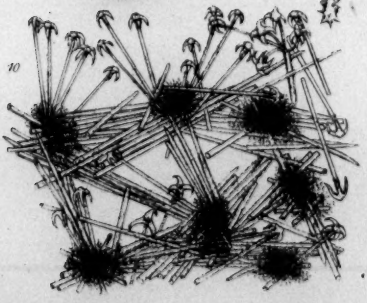

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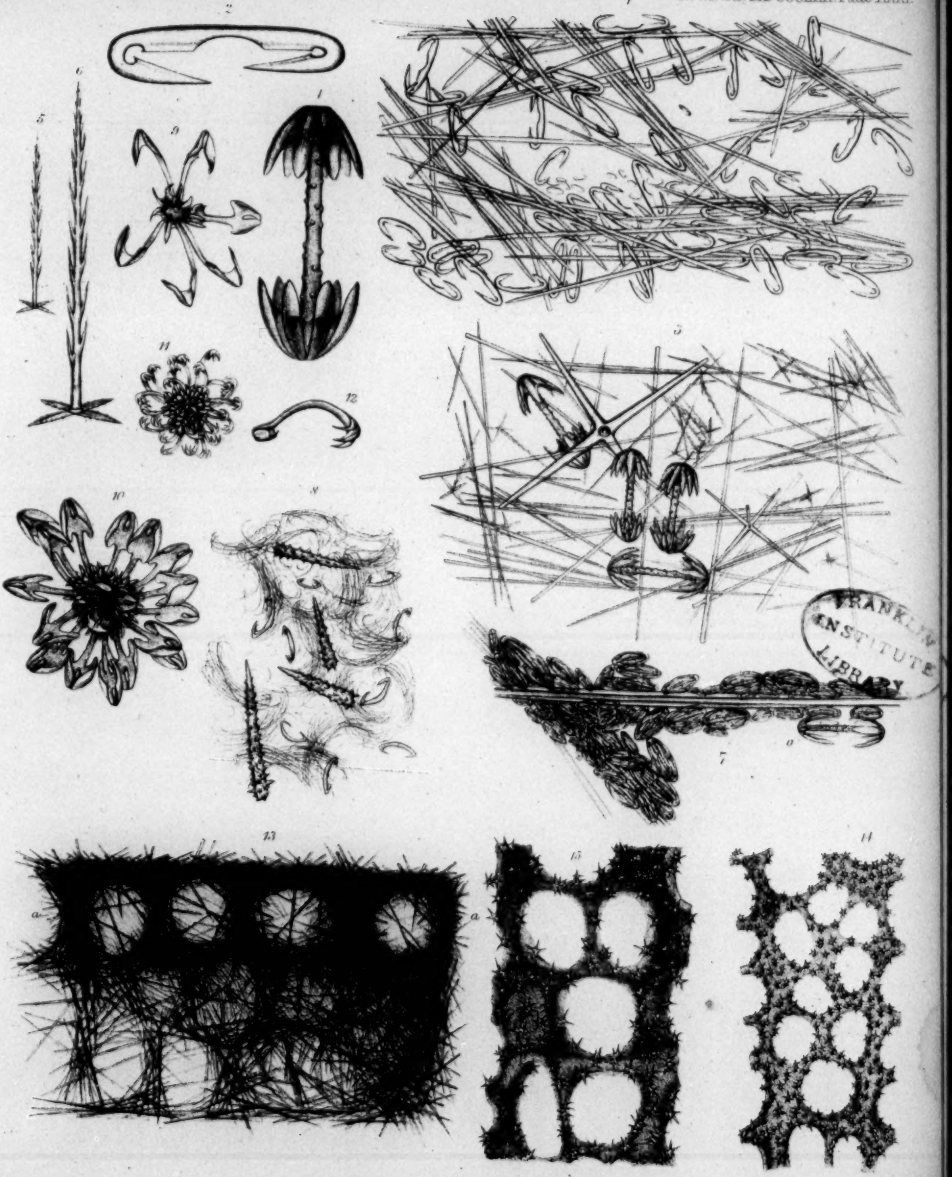

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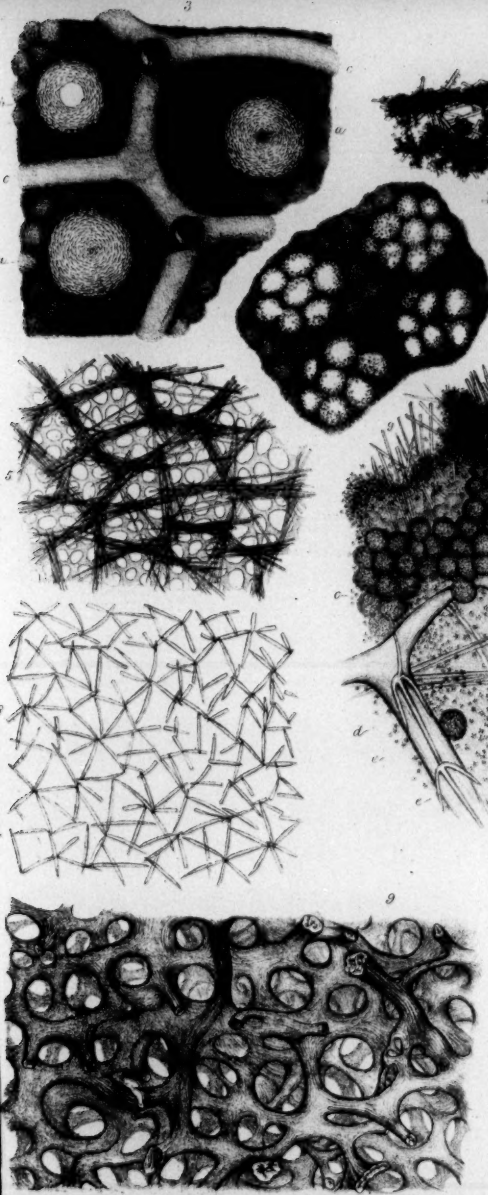

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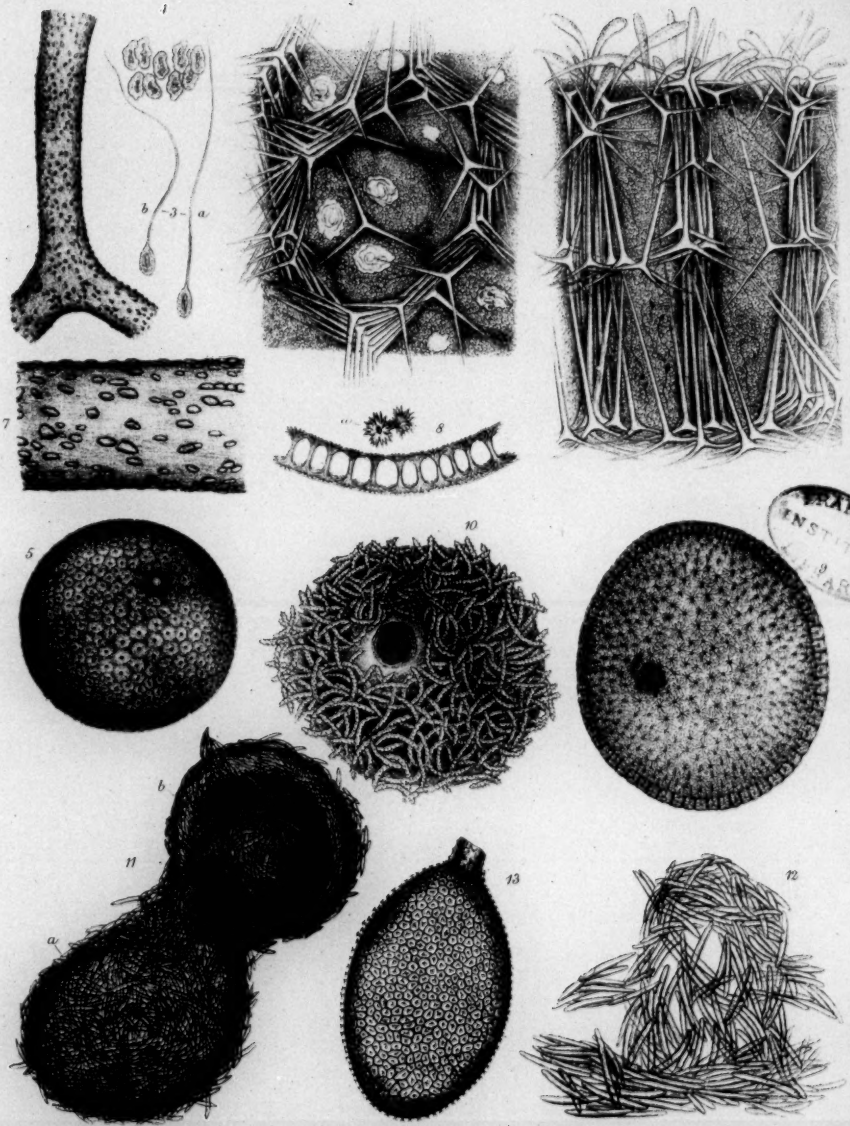

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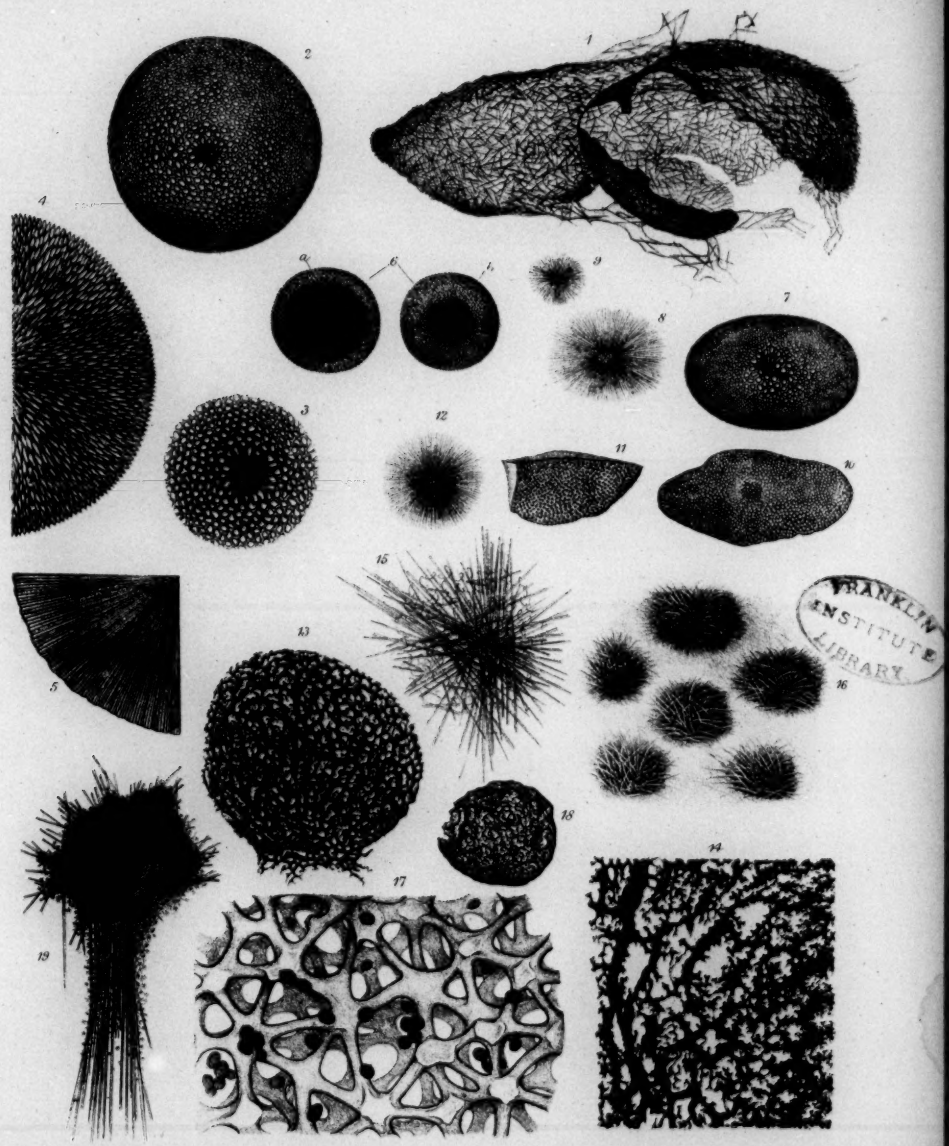

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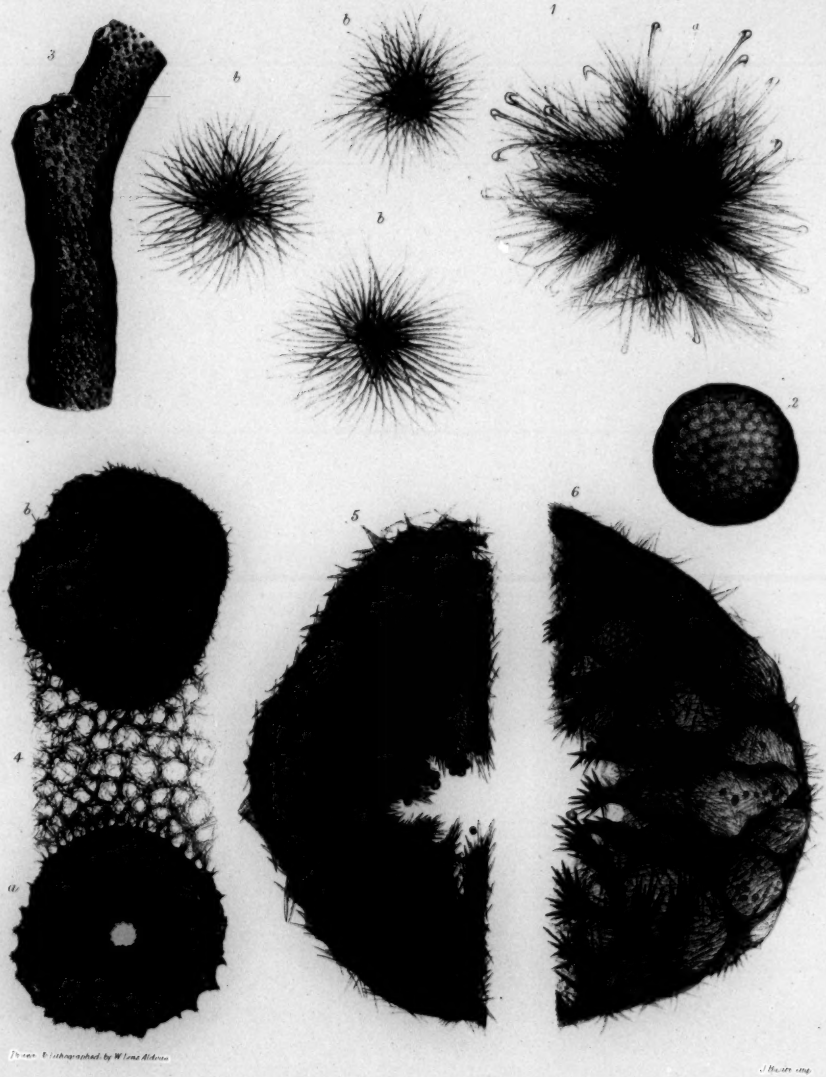

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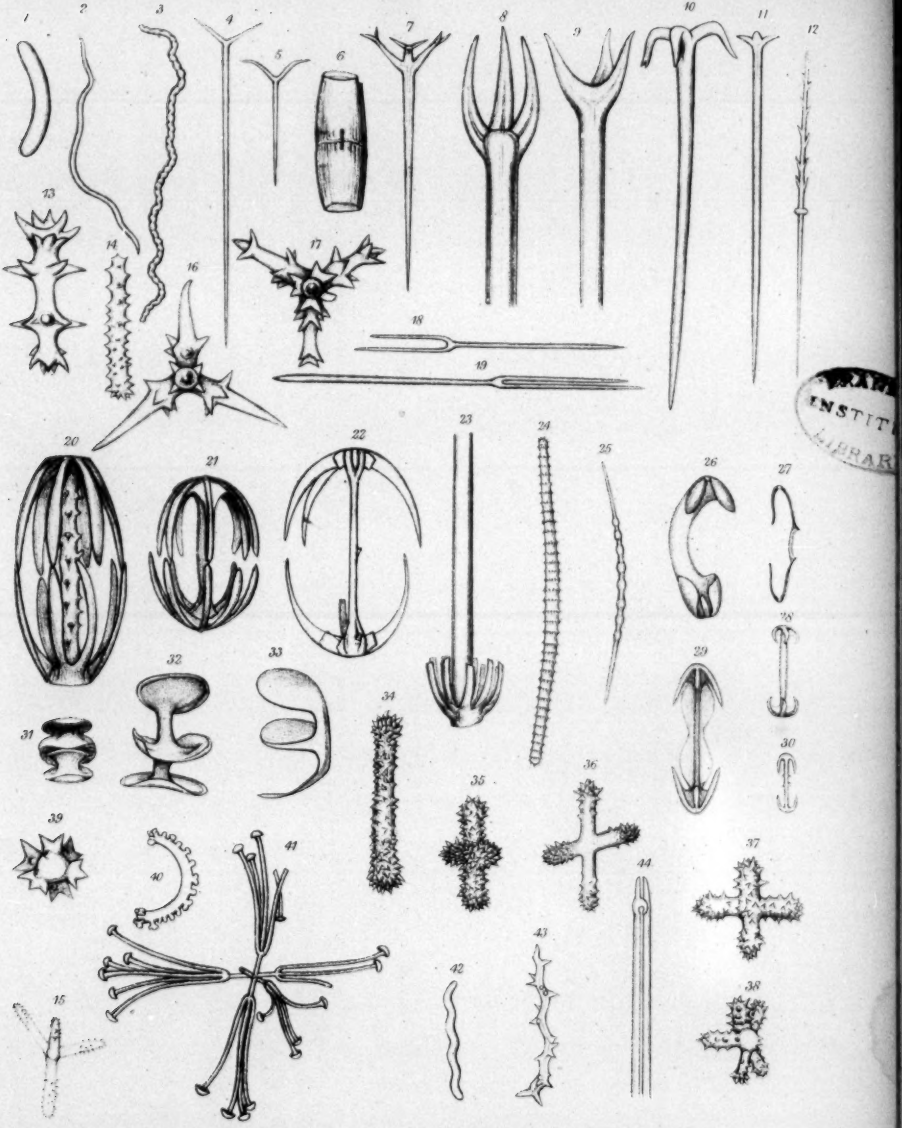

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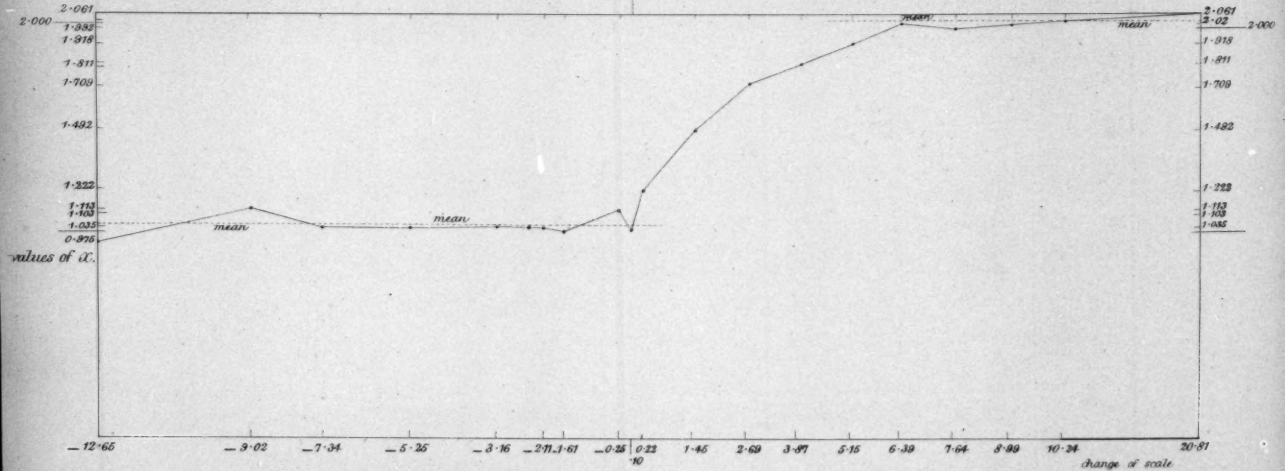

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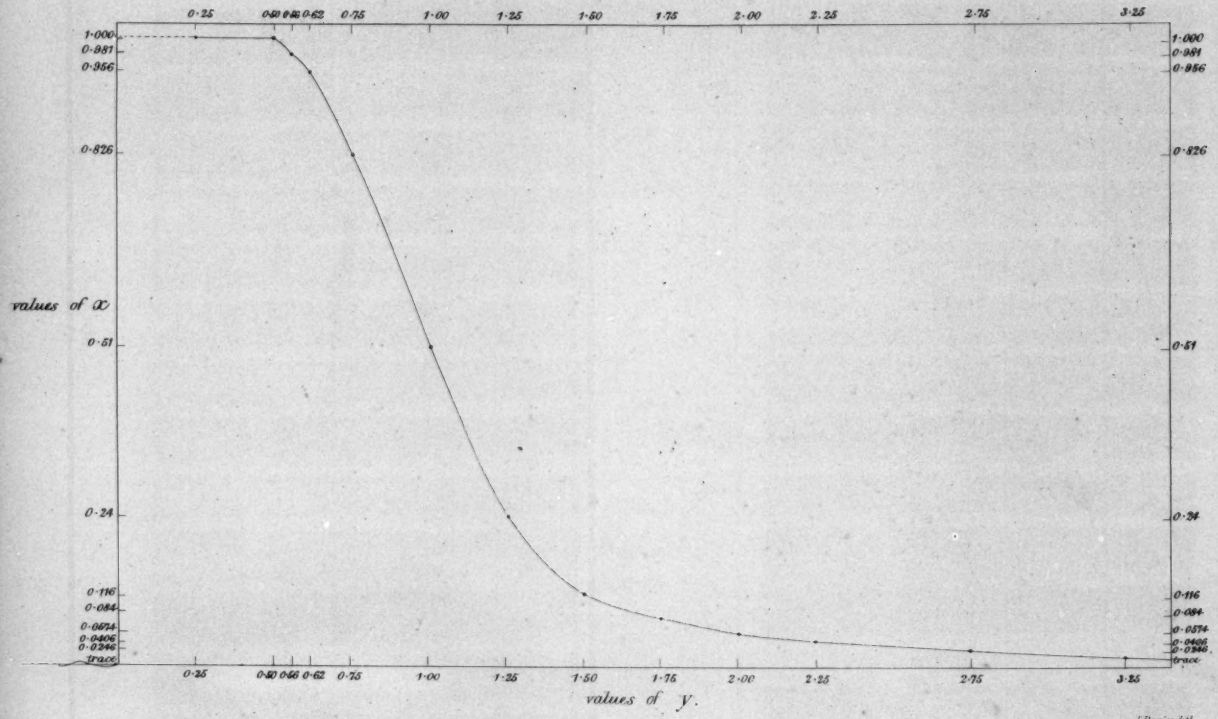

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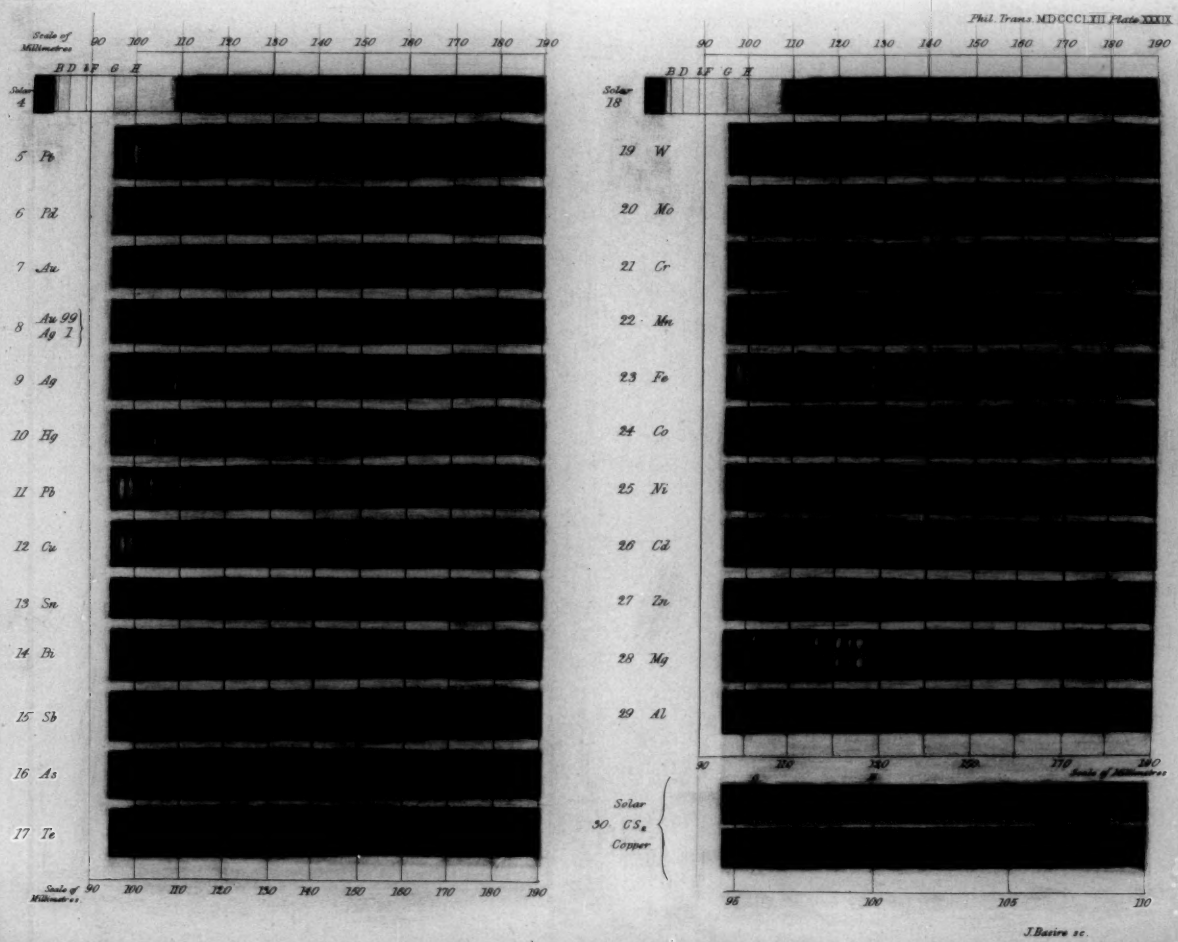
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6 Pd
7 Au
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17 Te
Solar 18
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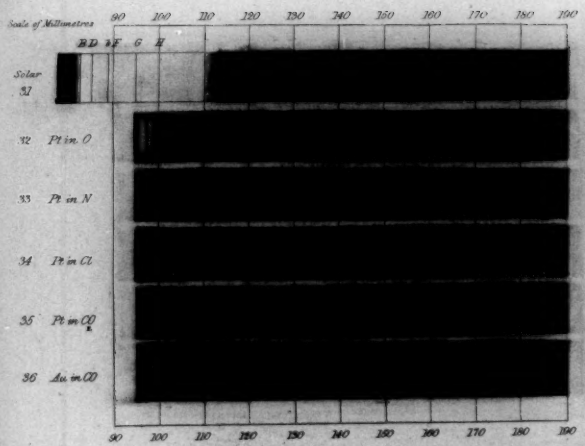
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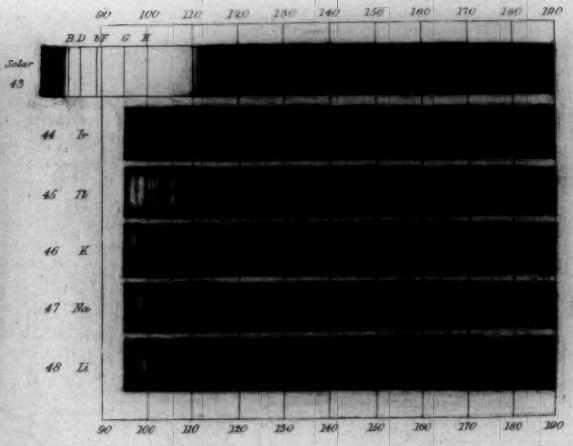
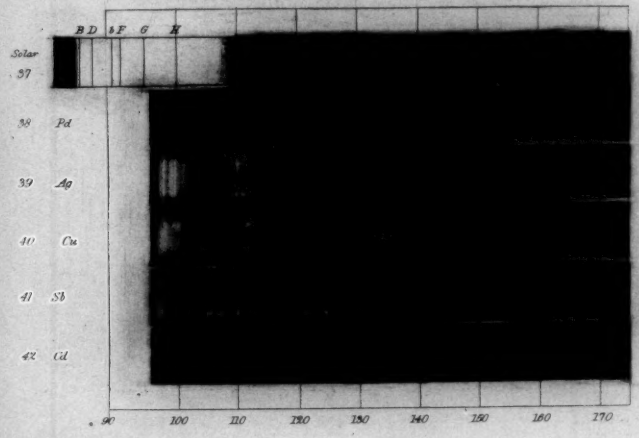
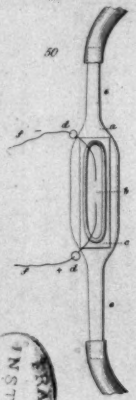
36 Au in CO







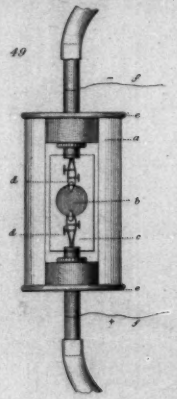


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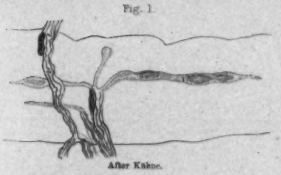
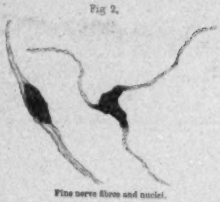
Fig. 1.



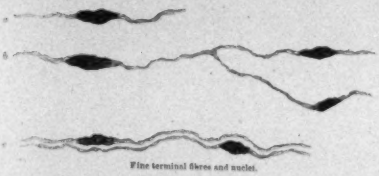
After Kühne.

Fig. 2.



Fine nerve fibres and nuclei.

Fig. 3.



Fine terminal fibres and nuclei.

Fig. 4.

Fig. 6.

Plexus of finest nerve fibres.—Bladder of frog. × 1700

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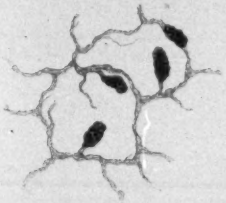
Fig. 5.



Possible mode of termination of finest nerve fibres.

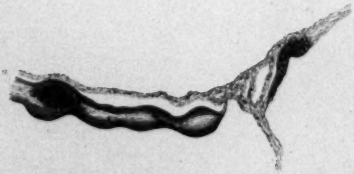
Fig. 7.

Terminal portion of dark-bordered fibre.—Bladder of frog. × 1700

Fig. 8.

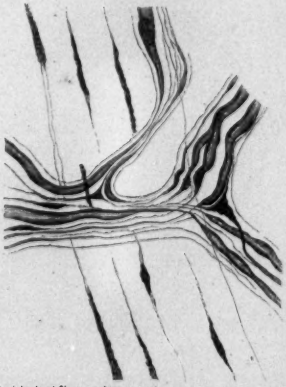
Terminal portion of dark-bordered fibre.—Bladder of frog. × 1700

Fig. 9.



Terminal portion of dark-bordered fibre.—Bladder of frog. × 1700

Fig. 10.



Dark-bordered fibres crossing a muscular fibre.—Leg of frog. × 1700

1000th ——— × 700

1000th ——— × 1700

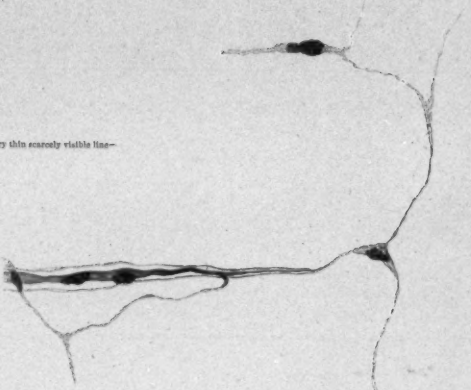
W. S. B. ad nat. del.

Harrison's Imp.

Fig. 11.

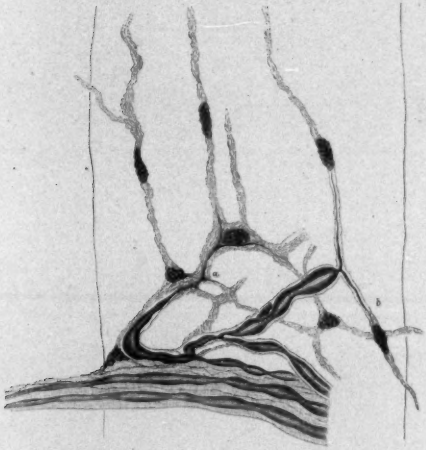
Division of dark-bordered nucleated fibres—at *a* a dark-bordered fibre contracts so as to form a very thin scarcely visible line—nuclei in dark-bordered fibres. × 700

Fig. 12.



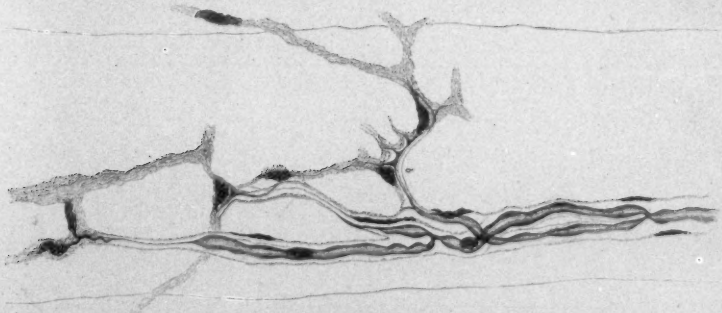
Division of dark-bordered fibre and fine nucleated fibres. × 700

Fig. 13.



Division of dark-bordered fibres on surface of a muscular fibre. × 700

Fig. 14.



Division and sub-division of fine dark-bordered nucleated fibres, and commencing portion of the network of pale nucleated fibres on surface of a muscular fibre. × 700

Fig. 15.

Junction of dark-bordered fibre and pale fibres of sheath. × 700

All these figures from the pectoral muscle of the frog.

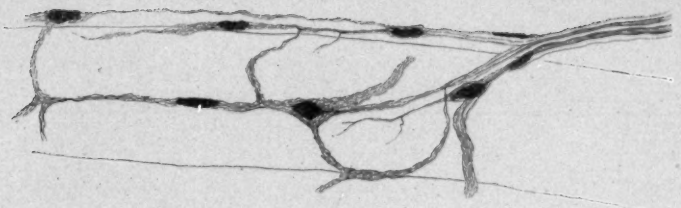
1000 th [illegible] × 700

1000 th [illegible] × 1700

H. S. B. ad nat. del.

(Harrison's Imp.

Fig. 16.

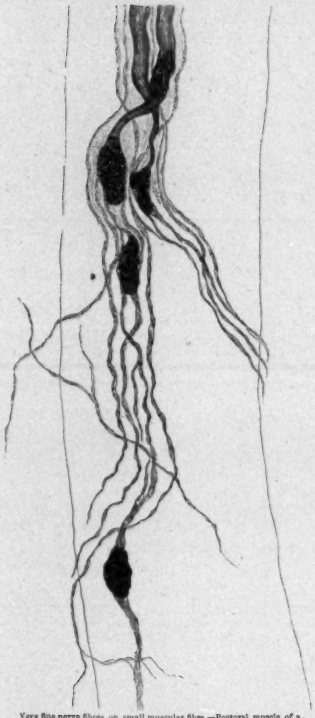


Terminal portion of finest dark-bordered fibres.—Small muscular fibre.—Pectoral. × 700

Fig. 17

Division of dark-bordered fibre, and fibres of sheath.—Formation of network.—Pectoral. × 700

Fig. 18.



Very fine nerve fibres on small muscular fibre.—Pectoral muscle of a young frog. × 1700

Fig. 21.

Thin dark-bordered fibre.—Fine fibres in sheath, crossing it and forming a branch which leaves the fibre.—From muscle of neck of frog. × 700

Fig. 22.

Fine fibres resulting from the sub-division of a dark-bordered fibre. × 700

Fig. 19.

Fine fibres ramifying in sheath, dividing and forming networks.—Muscle from the neck of the frog. × 700

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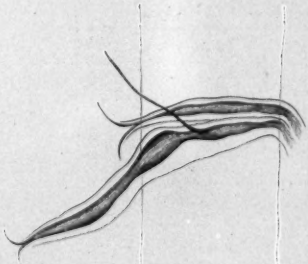
Fig. 23.



Division of dark bordered fibres while crossing a muscular fibre. × 700

Fig. 20.

Division of dark-bordered fibre and network of fine fibres.—Pectoral muscle. × 700

1000 th ——— × 700

1000 th ——— × 1700

Fig. 24.

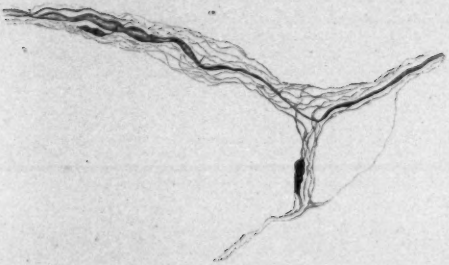
Fine fibre in same sheath with dark-bordered fibre. × 700

Fig. 25.

Fig. 26.

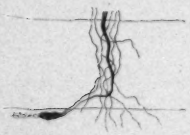
Dark-bordered fibres and fine fibres in sheath. × 700

Fig. 27.



Fine dark-bordered fibre and fine nerve fibres in sheath. × 700

Fig. 28.



Terminal portion of dark-bordered fibre with fine fibres crossing a young muscular fiber. × 700.

Fig. 29.

Branching and division of dark-bordered fibres and pale fibres in same sheath.—From bladder of the frog. × 700

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Fig. 30.

Young muscular fibres near a nerve swelling.—Pectoral of frog.—Shewing division of nerve fibres at another fibre at a distance from the nerve swelling. × 700

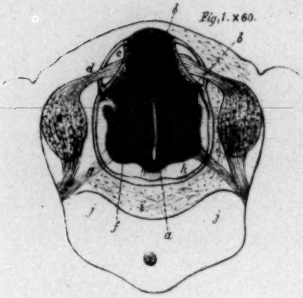
Fig. 31.

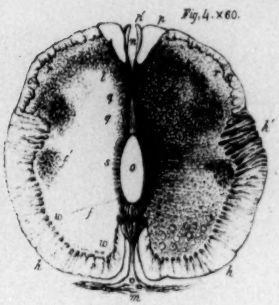
Dark-bordered nerve fibre with a bundle of fine fibres by the side of it. Bladder of frog. × 700

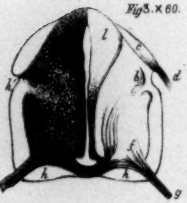
1000th [illegible] × 700

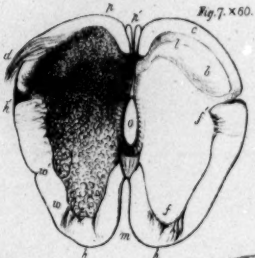
1000th [illegible] × 1700

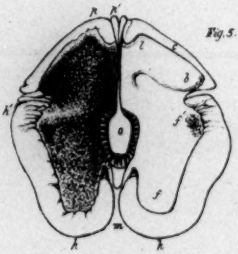
[Harrison's Impl.

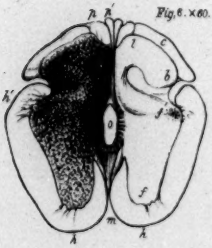


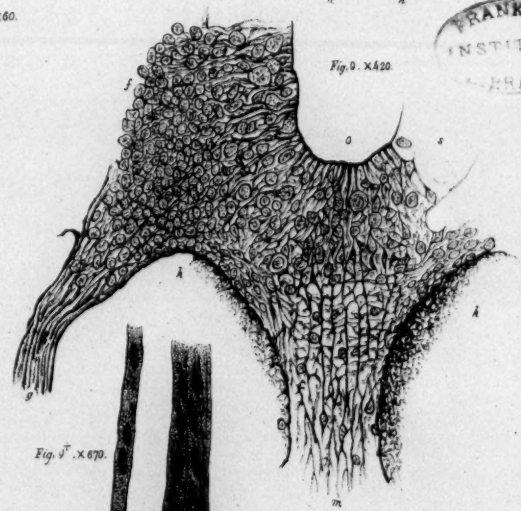












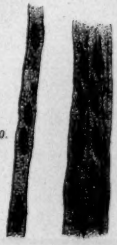


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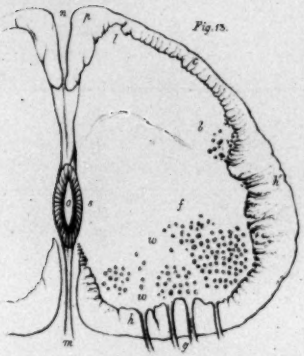
Fig. 13.



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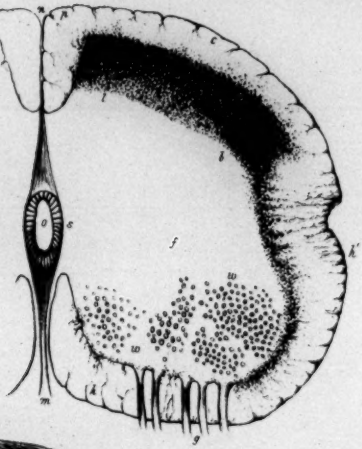

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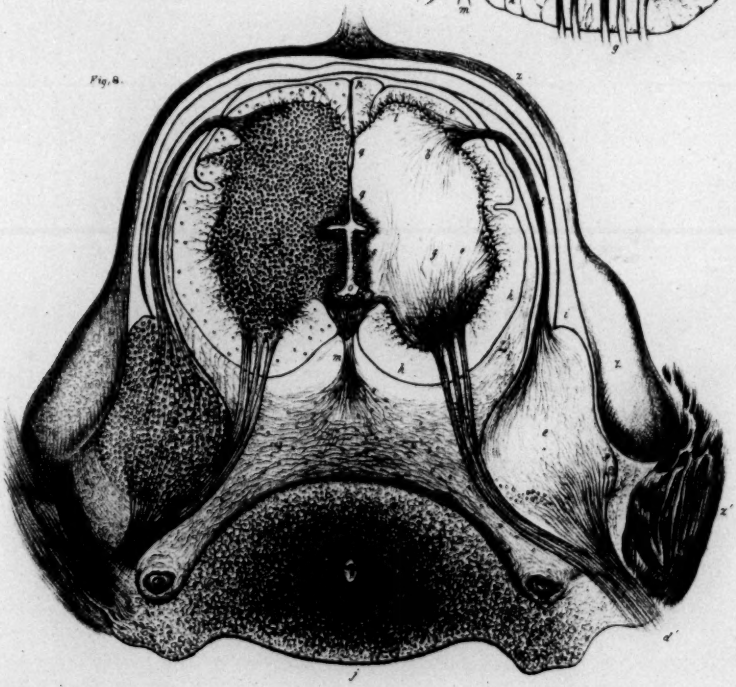

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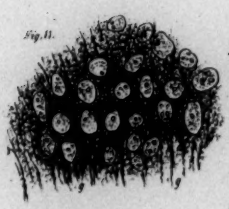
Fig. 11.

Fig. 17.

Fig. 17*

I

Fig. 26.

Fig. 23.

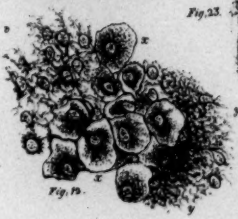
Fig. 19.

Fig. 27

Fig. 15.
II

Fig. 24.

Fig. 16.

Fig. 24*

Fig. 29.

Fig. 28.

III

Fig. 18.

Fig. 25.

Fig. 25.*

Fig. 21.

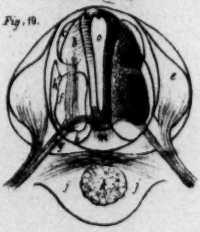
Fig. 19.

Fig. 22.

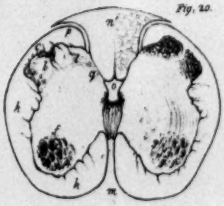
Fig. 20.

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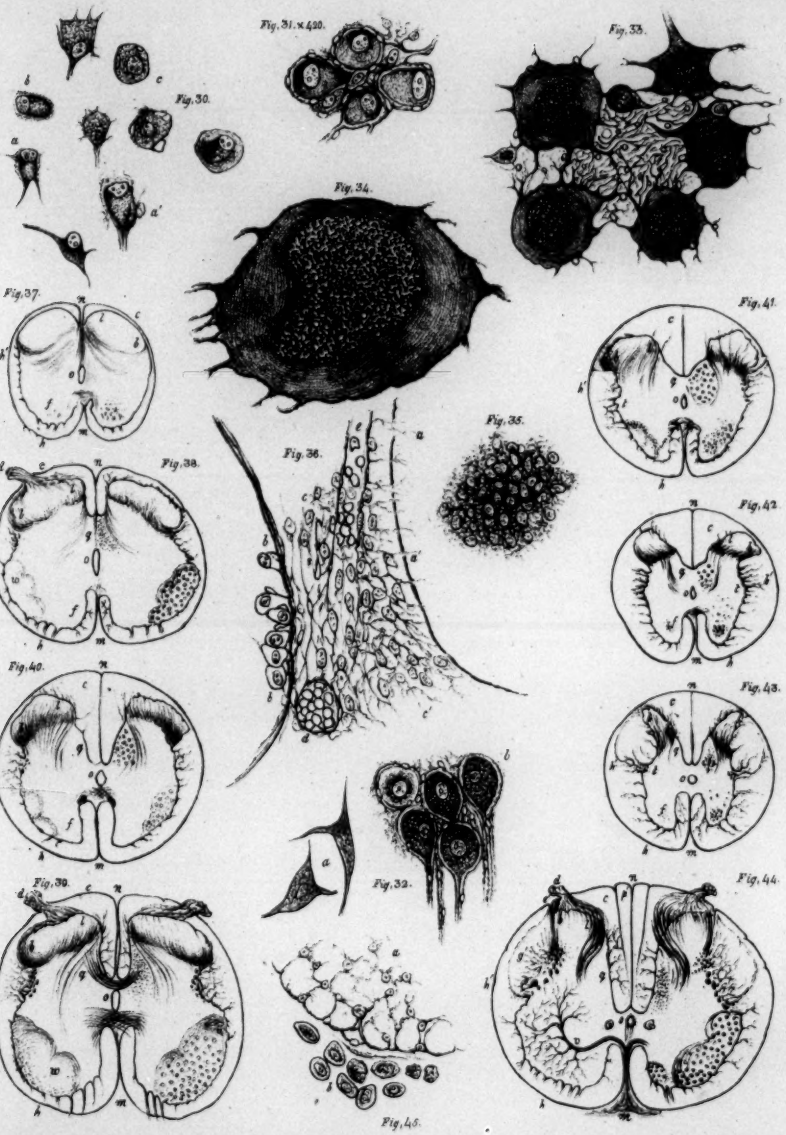

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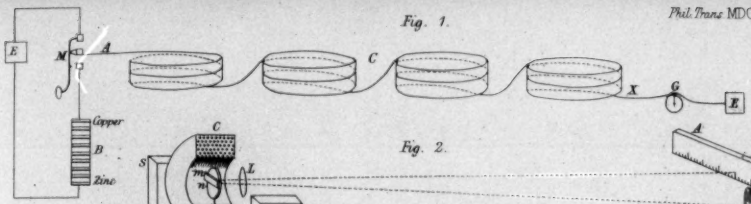
E.M.Williams, Sc.

Fig. 1.



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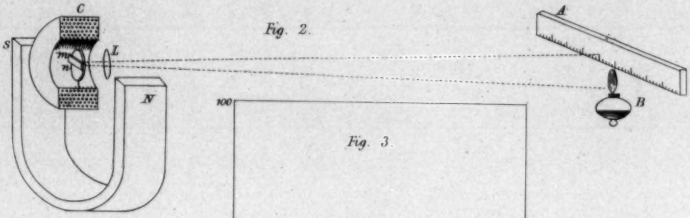

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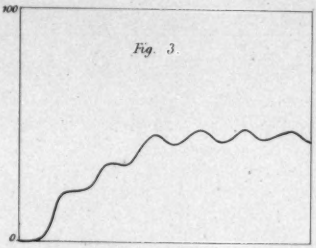

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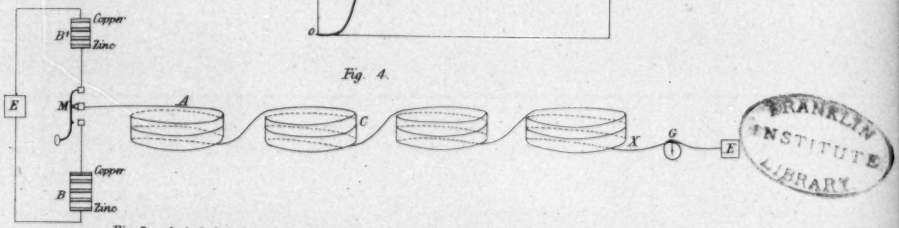

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Fig. 5. *Arrival-Curve for 1165 knots from Positive currents & Earth contacts.*

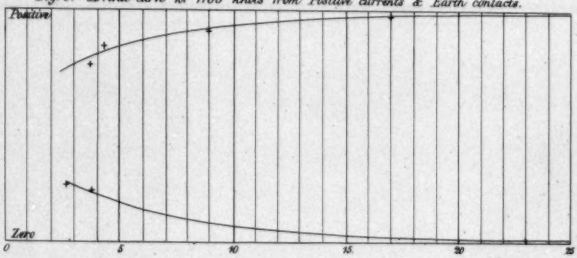

Fig. 6. *Arrival Curve for 1165 knots from Positive and Negative Currents.*

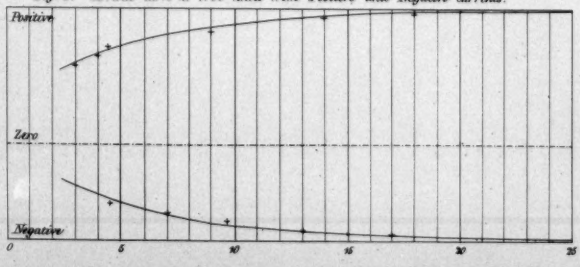

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Fig. 7. Arrival-Curve for 1006 knots in 4 Coils and 2102 knots in 10 Coils.

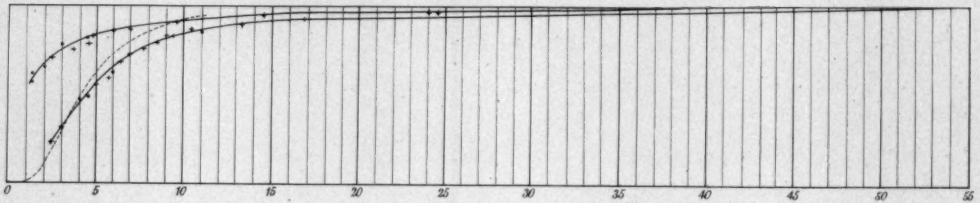

Fig. 8.

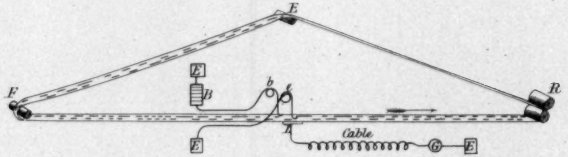

Fig. 9. Paper used to make contacts. ½ full size.

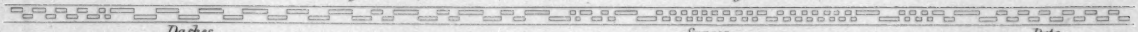

Fig. 10. Signals received from paper in Fig. 9.

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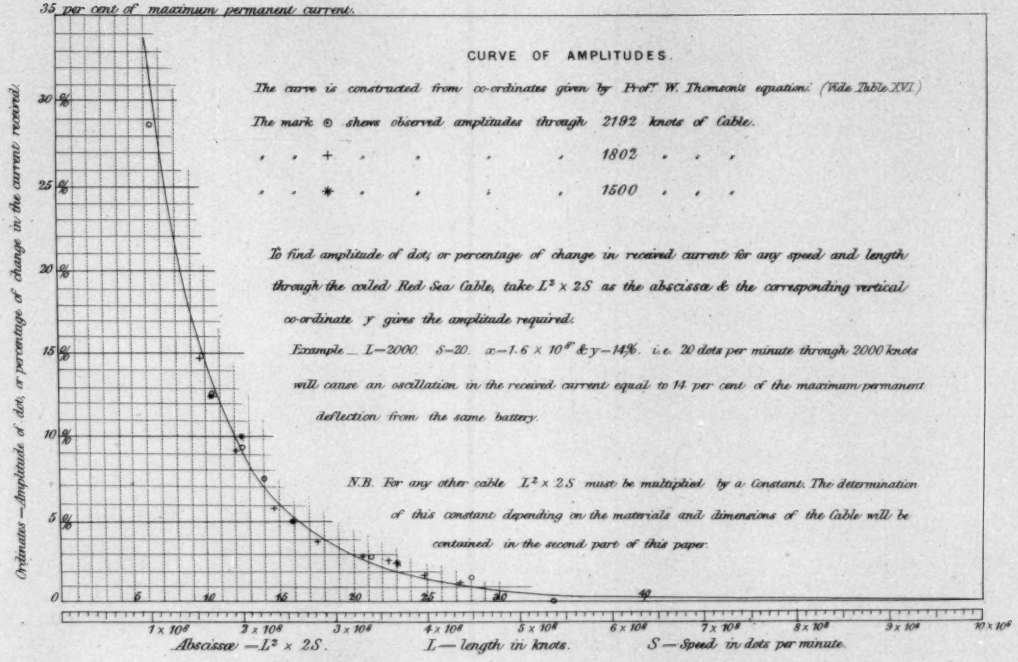
Phil. Trans. MDCCCXL. Plate 11.

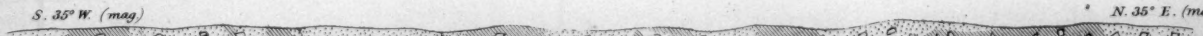
Fig. 11.

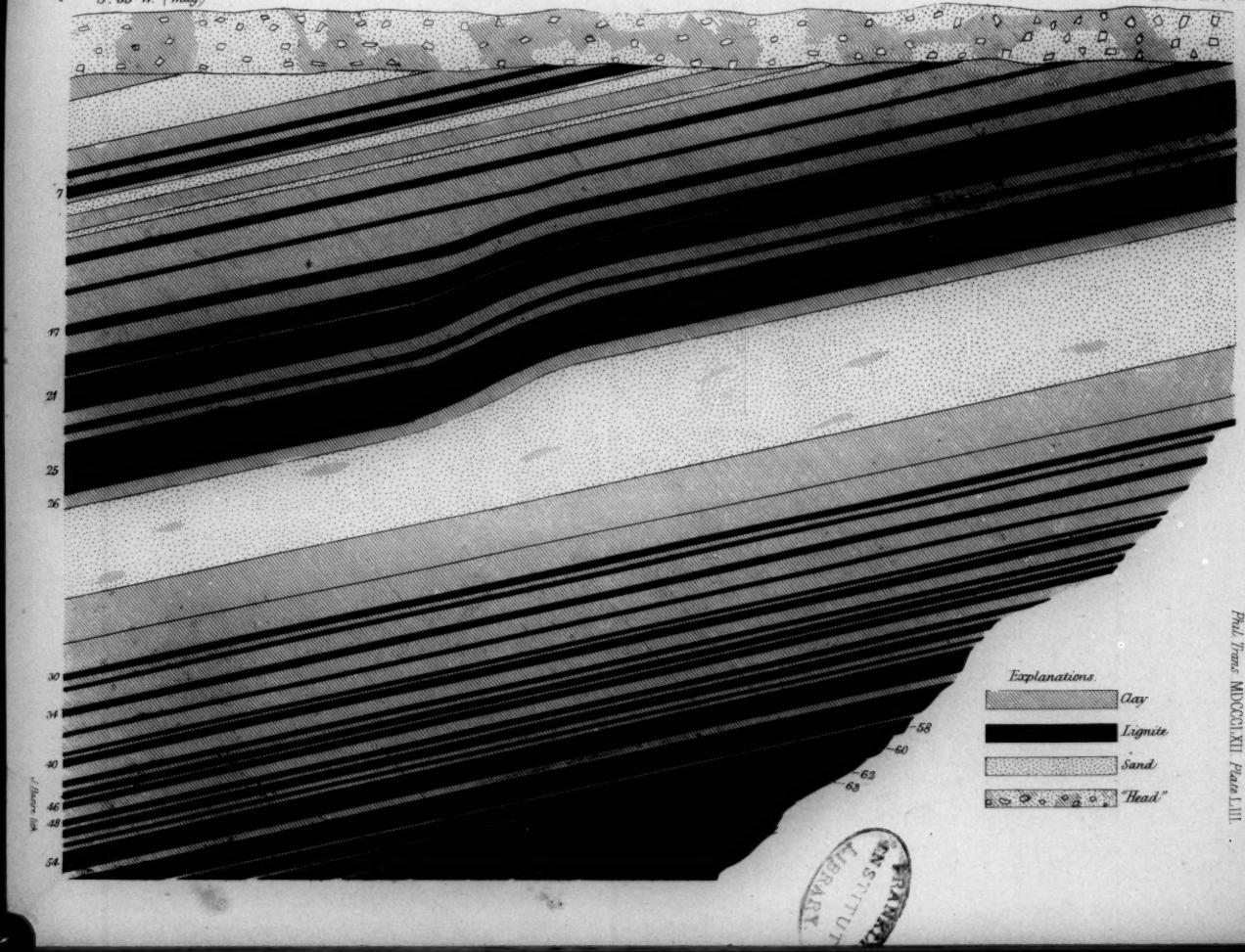

35 per cent of maximum permanent current.
CURVE OF AMPLITUDES.
The curve is constructed from co-ordinates given by Prof. W. Thomson's equation. (Vide Table XVI.)
The mark ⊙ shows observed amplitudes through 2192 knots of Cable.
" " + " " " " 1802 " " "
" " * " " " " 1500 " " "
To find amplitude of dot, or percentage of change in received current for any speed and length through the coiled Red Sea Cable, take L² × 2S as the abscissa & the corresponding vertical co-ordinate y gives the amplitude required.
Example.— L=2000. S=20. x=1.6 × 10⁶ & y=14%. i.e. 20 dots per minute through 2000 knots will cause an oscillation in the received current equal to 14 per cent of the maximum permanent deflection from the same battery.
N.B. For any other cable L² × 2S must be multiplied by a Constant. The determination of this constant depending on the materials and dimensions of the Cable will be contained in the second part of this paper.
(Ordinates — Amplitude of dot, or percentage of change in the current received.
30 %
25 %
20 %
15 %
10 %
5 %
0
5
10
15
20
25
30
40
1 × 10⁶
2 × 10⁶
3 × 10⁶
4 × 10⁶
5 × 10⁶
6 × 10⁶
7 × 10⁶
8 × 10⁶
9 × 10⁶
10 × 10⁶
Abscissæ — L² × 2S.
L — length in knots.
S — Speed in dots per minute.

The dotted lines give the number of dots per minute in function of x (vide Appendix II.) & Table XVI.

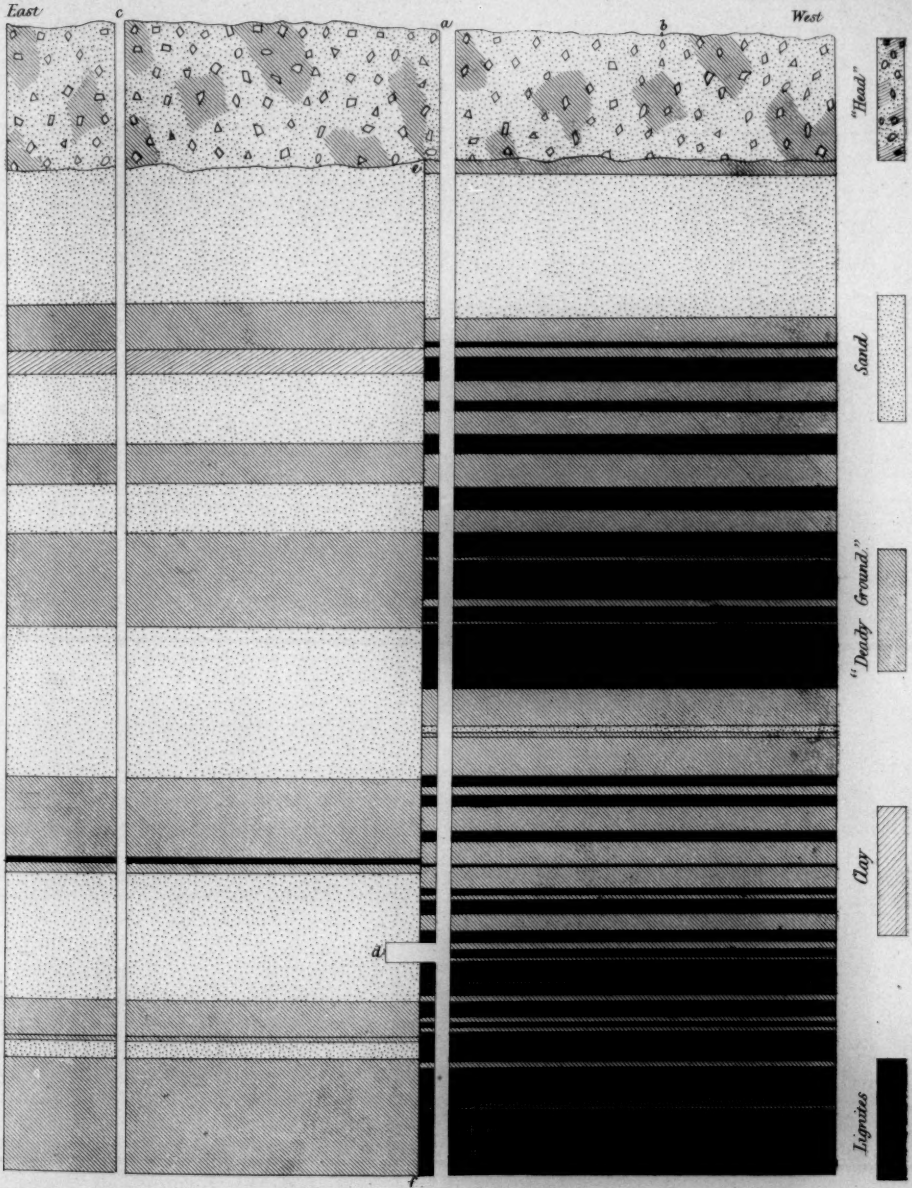
J. Basire lith.

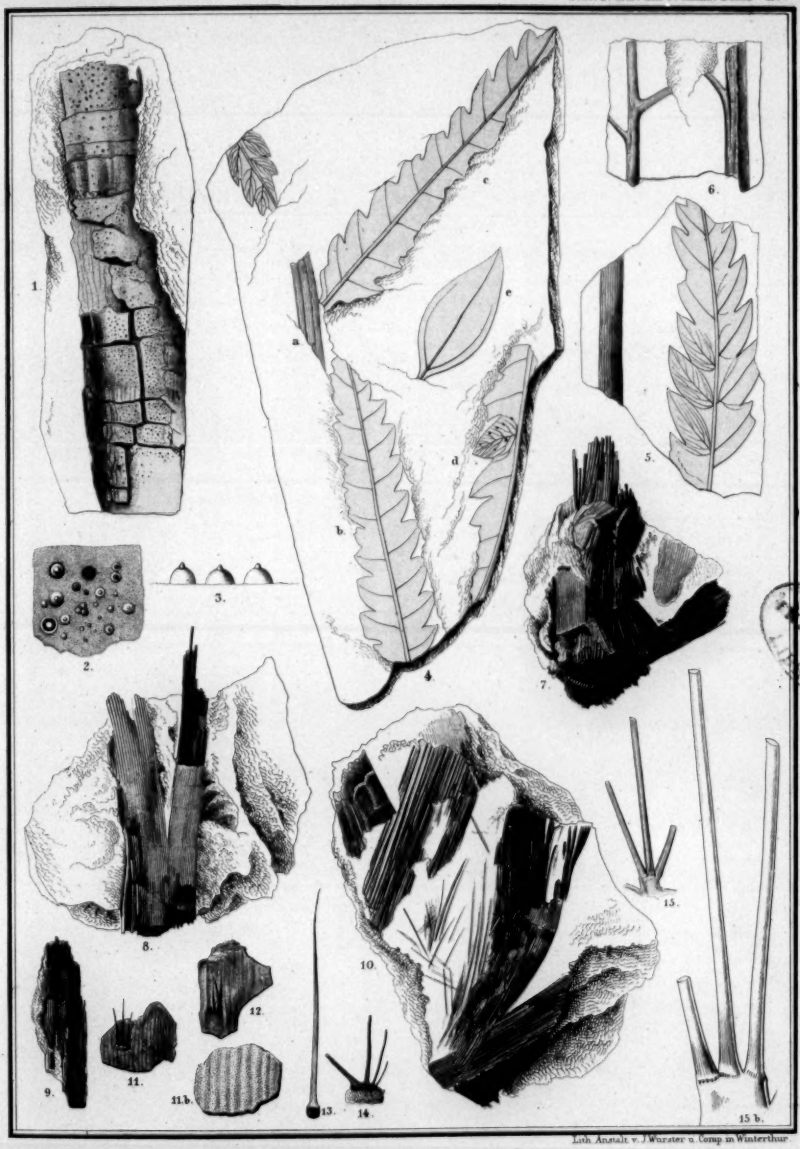
W. West, 54b Hatton Garden.


S. 35° W. (mag)
N. 35° E. (mag.)



Phil. Trans. MDCCCLXII. Plate LIII.


East
c
a
b
West
"Head"
Sand.
"Deadv Ground."
Clay
Lignites
d
f
J. Basire lith.



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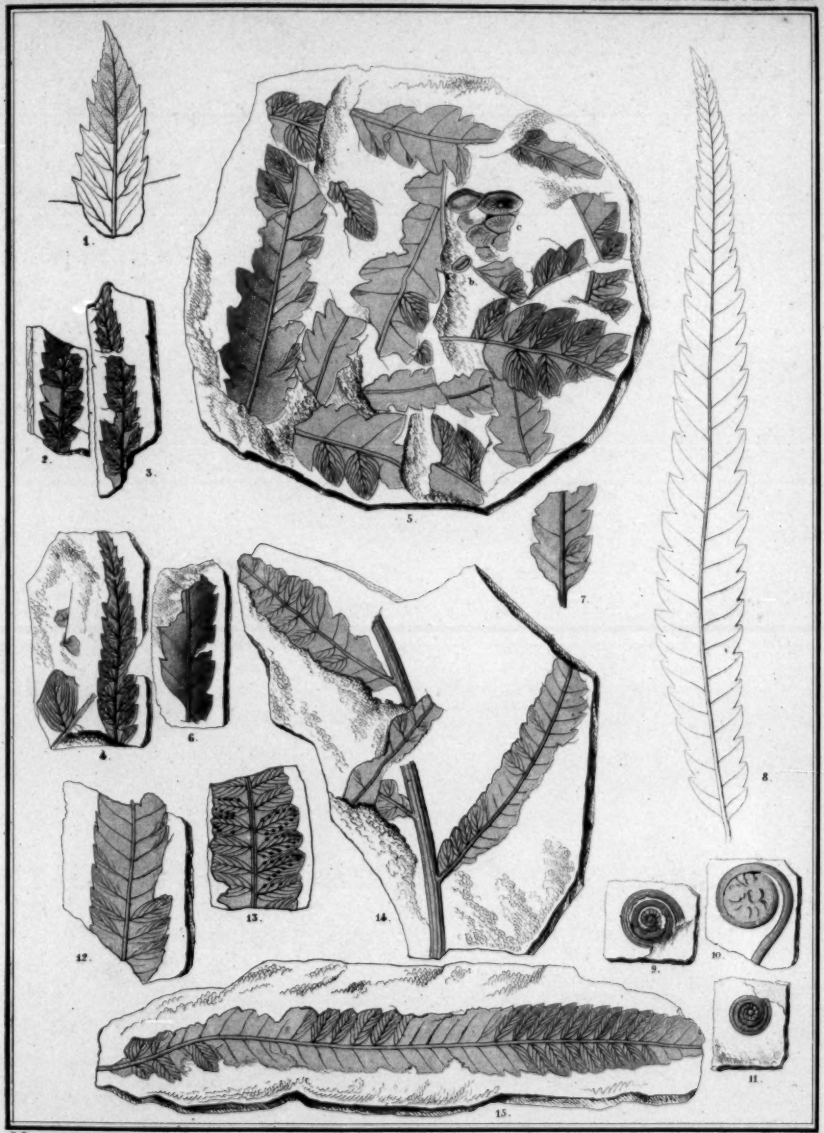
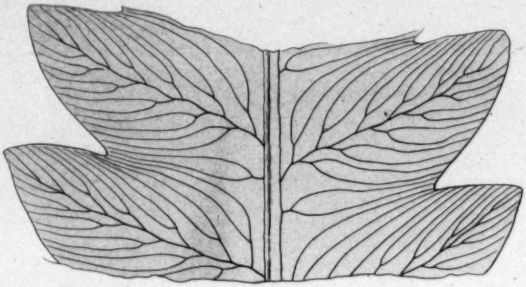
1. 2. 3. Sphaeria lignitum. 4 a–d. Pecopteris lignitum. 4. e. Cinnamomum Scheuchzeri. 5. 6. Pecopteris lignitum. 7–15. Palmacites Daemonorops.



P. Bengier del.

Lith. Anstalt v. J. Wurster u. Comp. in Winterthur.

1 – 11. Pecopteris lignitum. 12 – 15. Lastraea stiriaca. 5. b. c. Sequoia Couttsiae.



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2.

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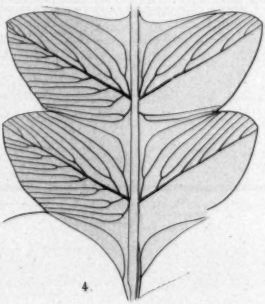

4.

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6.

7.

8.

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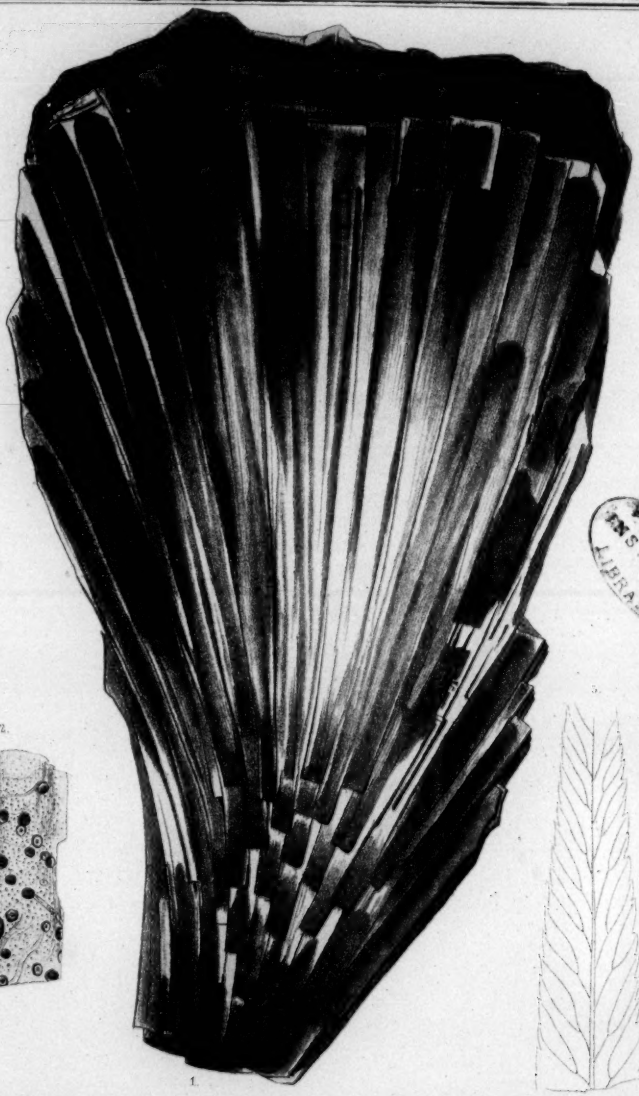
Ch. Th. Gaudin et W. Fisch del. Lith. Anstalt v. J. Wurster u. Comp. in Winterthur.

1–7. Pecopteris lignitum. 8. Lastraea styriaca.



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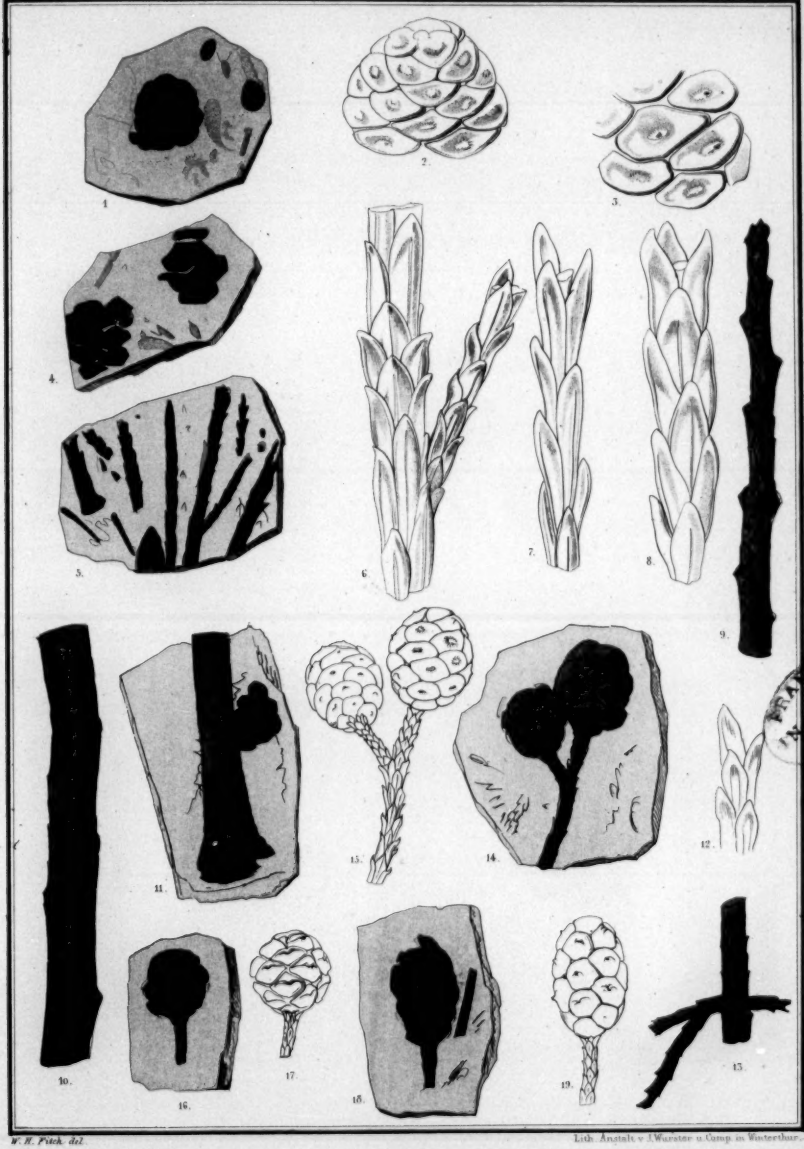
W. H. Fitch del. Lith. Anstalt v. J. Wurster u. Comp. in Winterthur

1–2 Pecopteris lignitum. 3. Pecopteris Hookeri.



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W. H. Fitch. del.

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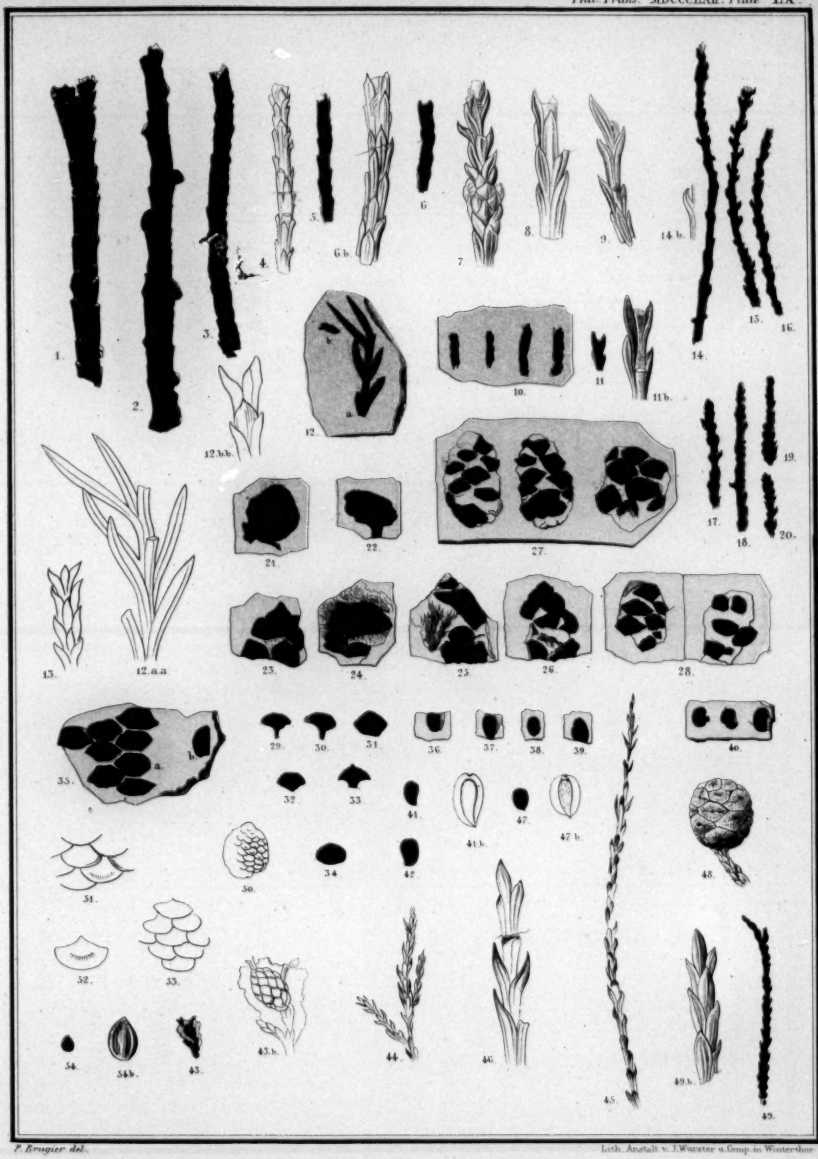
Sequoia Couttsiae



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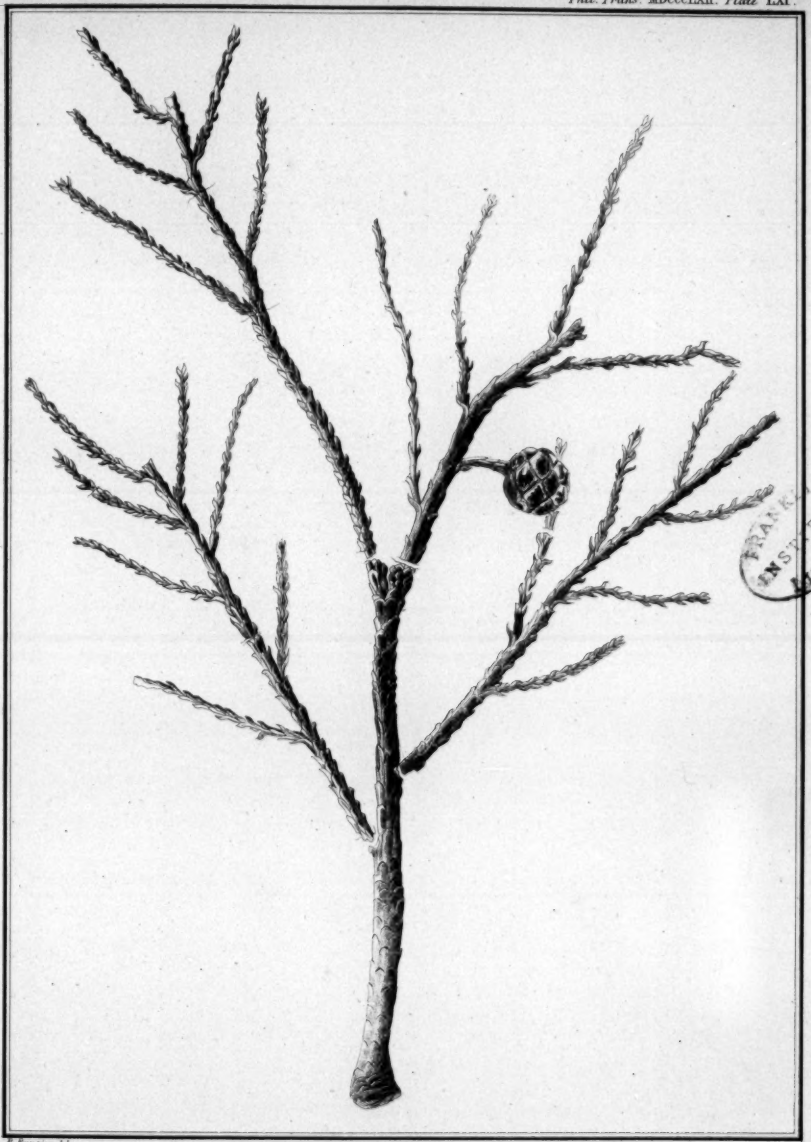
1–46. Sequoia Couttsiae. 47.48. Sequoia sempervirens. 49. Glyptostrobus europaeus. 50–53. Palmacites Daemonorops ?. 54. Cyperites deperditus.



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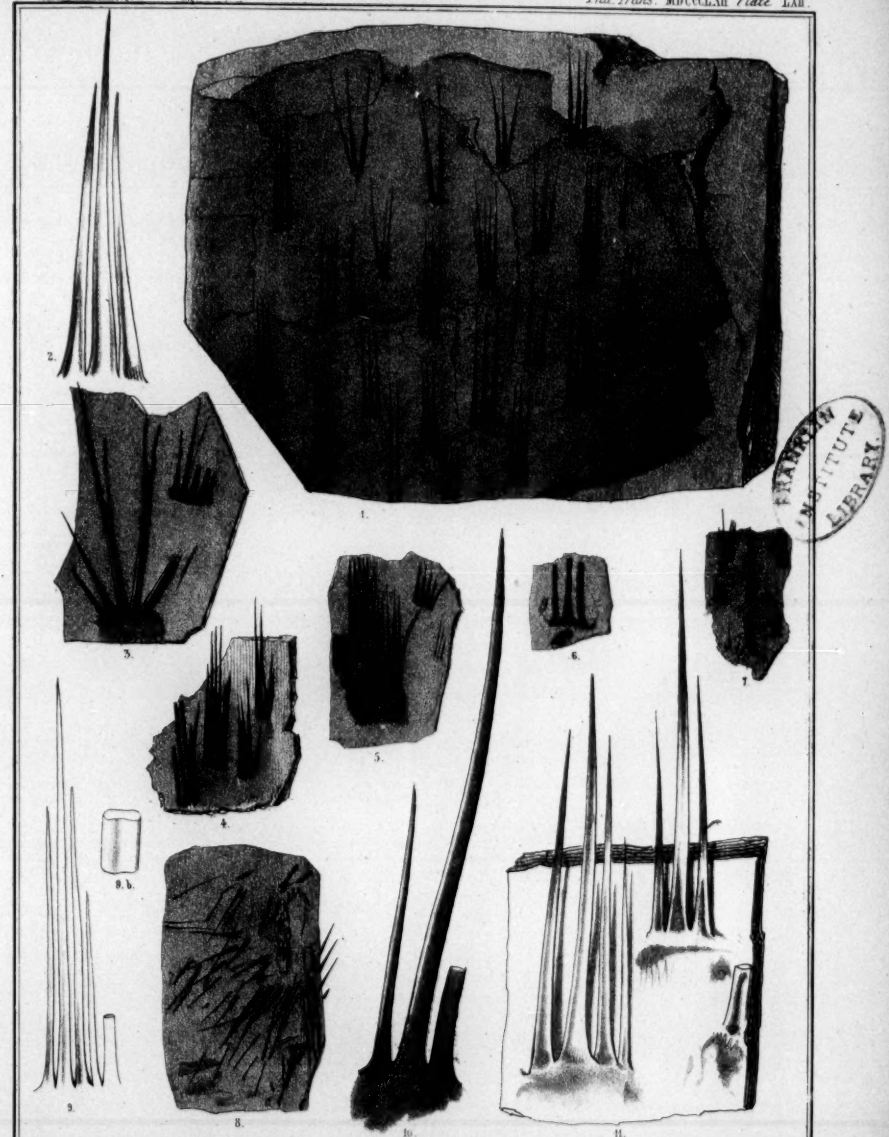
F. Bruguier del.

Lith. Anstalt v. J. Wurster & Comp. in Winterthur.

Sequoia Gouttsiæ.



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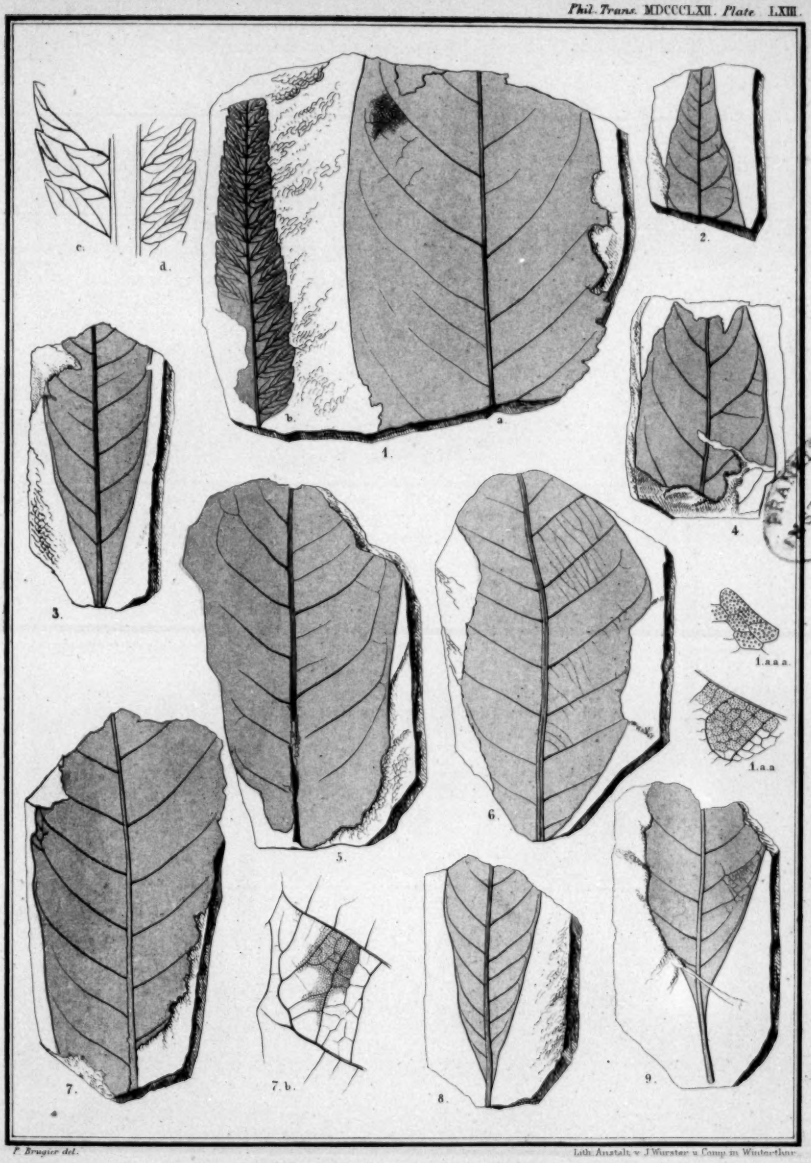
W. H. Fitch. del.

Lith. Anstalt v. J. Wurster u. Comp. in Winterthur.

Palmacites Daemonorops



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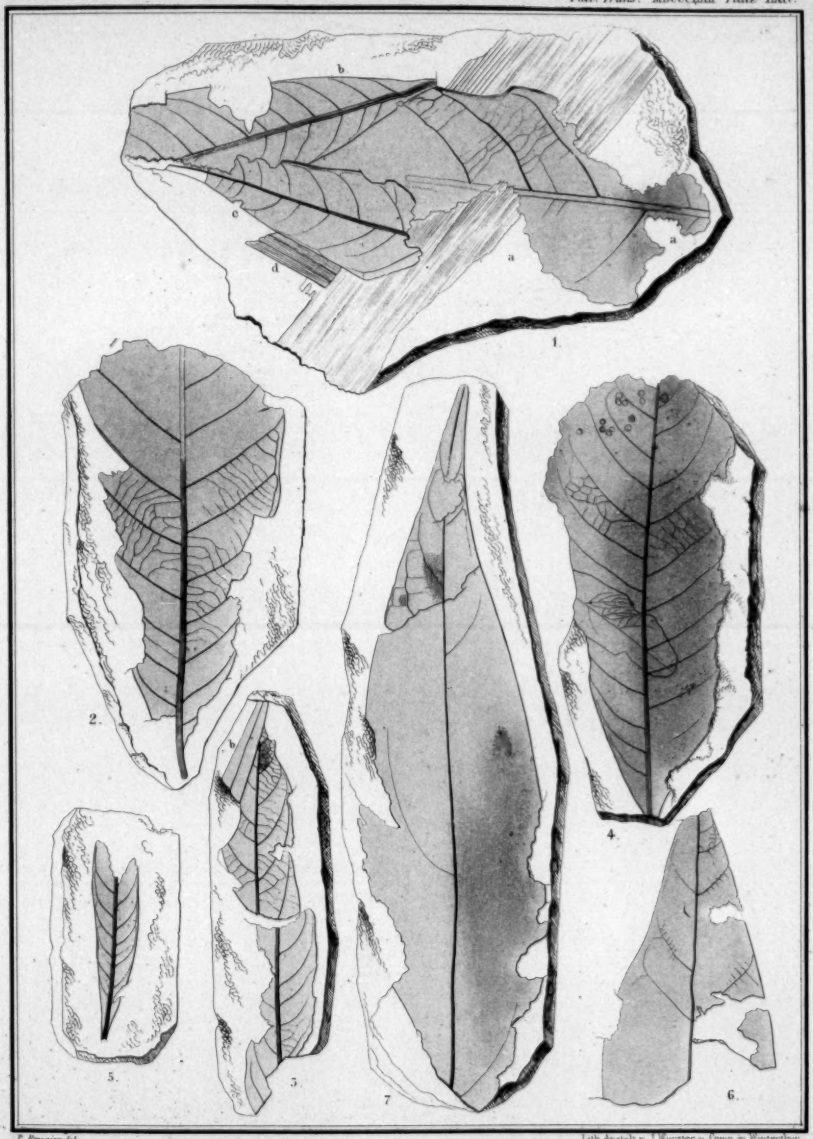
P. Brugier del.

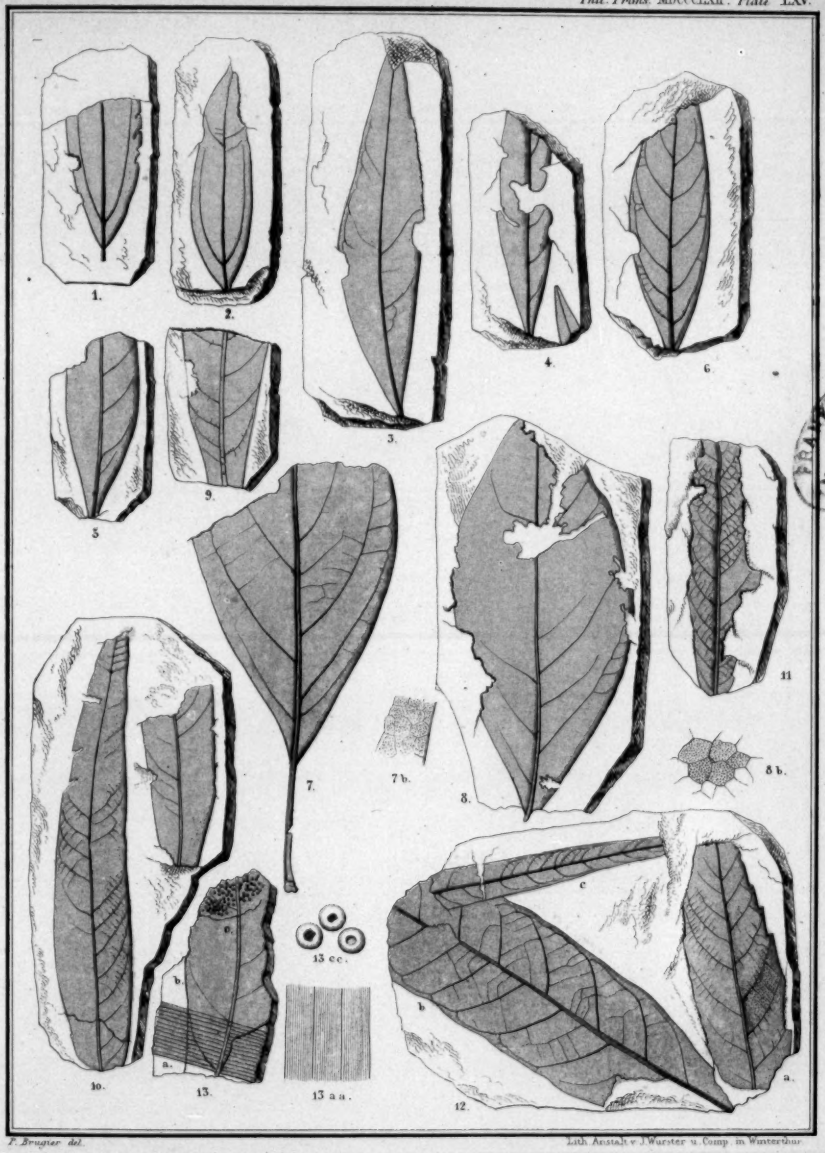
Lith. Anstalt v. J. Wurster u. Comp. in Winterthur.

1. b. d. Lastraea Bunbarii. 1. a. Ficus Falconeri 2–9. Quercus Lyelli.



P. Bruyère del. Luth. Anstalt v. J. Wurster u. Comp. in Winterthur

1. a.b.c. Quercus Lyelli. 1 d. Phragmites oeningensis 2.3.a.4. Quercus Lyelli. 3 b.5. Echitonium cuspidatum. 6.7. Ficus Falconeri.



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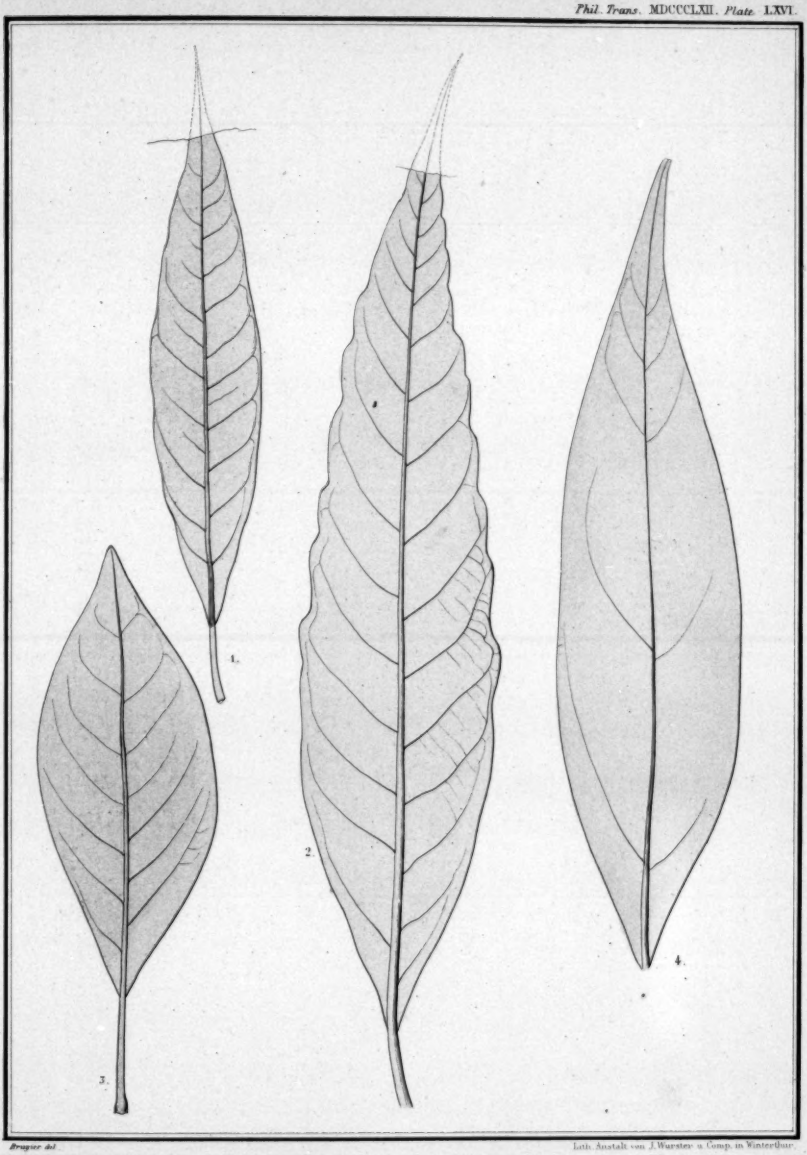
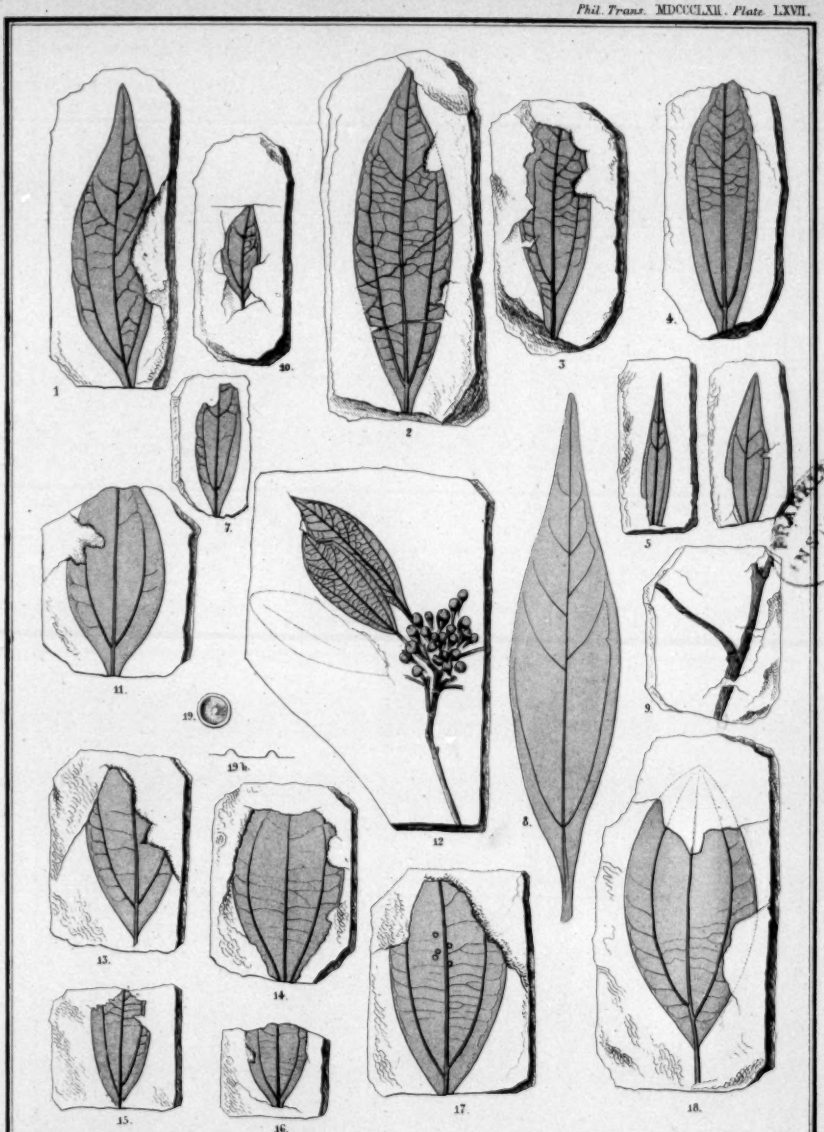
1. 2. Daphnogene Ungeri. 3. 4. 5. Ficus eucalyptoides. 6. Laurus primigenia. 7. 8. Ficus Pengellii. 9–11. Dryandroides laevigata. 12. a. Dryandroides hakeaefolia. 12. b. Quercus Lyellii. 12. c. Echitonium cuspidatum. 13. a. Phragmites oeningensis ? 13. b. Dryandroides laevigata. 13. c. Sphaeria socialis.



Bruyer del.

Lith. Anstalt von J. Wurster & Comp. in Winterthur.

1. 2. Quercus Lyelli. 3. Ficus Pengellii. 4. Ficus Falconeri



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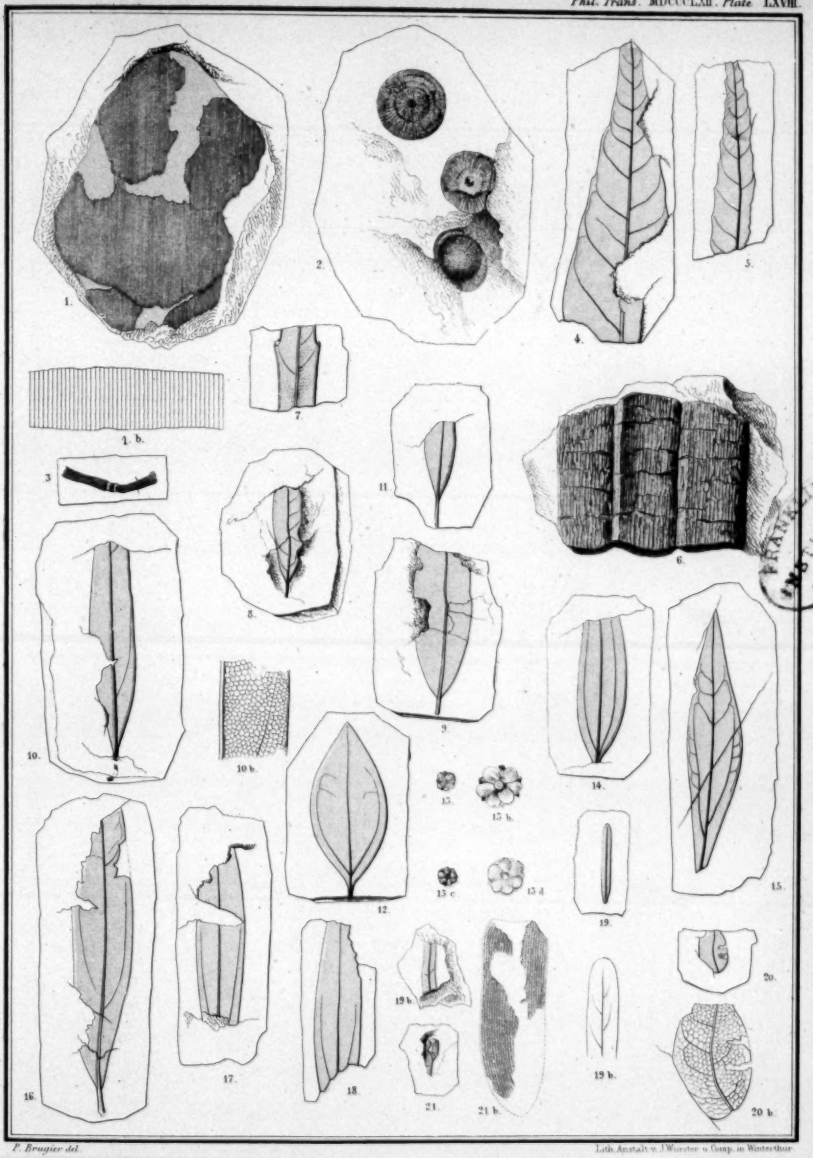
P. Brugier del.

Lith. Anst. d. J. Wurster u. Comp. in Winterthur

1–8. Cinnamomum lanceolatum. 9–16. Cinnamomum Scheuchzeri. 17.18. Cinnamomum Rossmässleri. 19. Sclerotium Cinnamomi.



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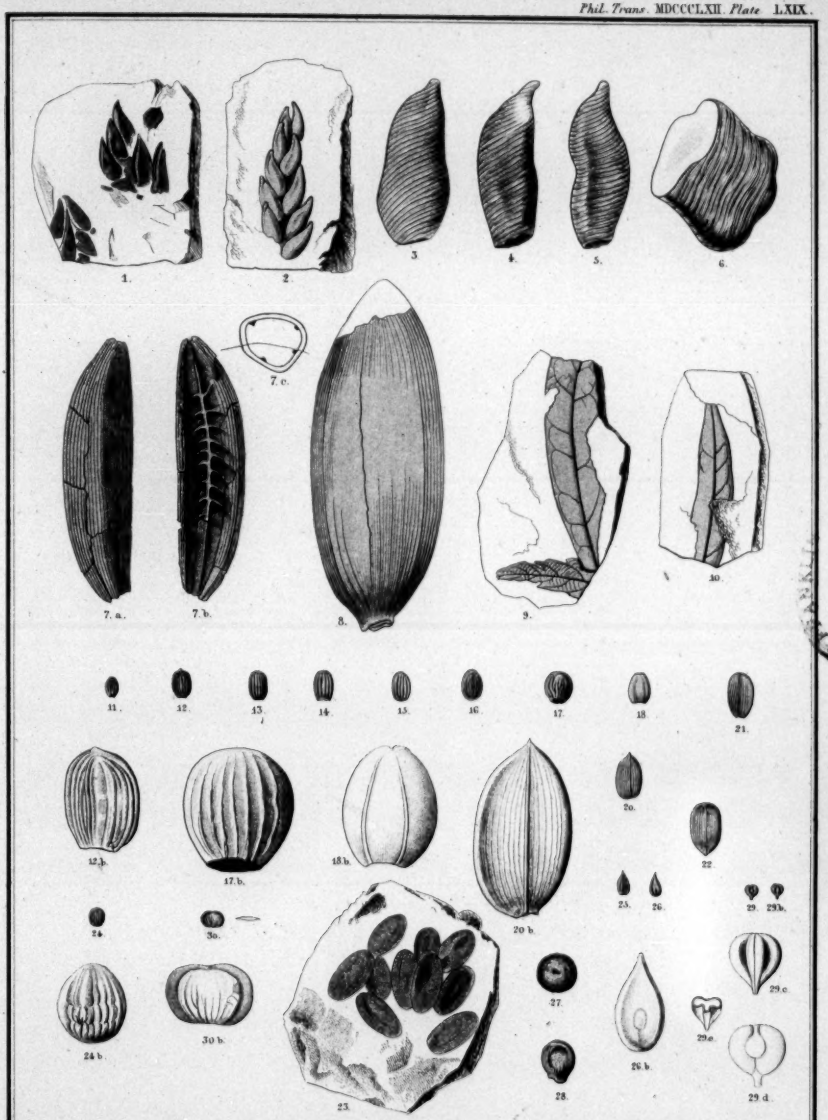
F. Brugier del. Lith. Anstalt v. J. Wurster u. Comp. in Winterthur.

1. Palmacites Daemonorops ? 2. Phragmites cerungensis ? 3. Poacites. 4.5.6. Quercus Lyelli. 7. Dryandroides banksiaefolia ? 8. Vaccinium acheronticum. 9. Andromeda vaccinifolia. 10. 11. Andromeda reticulata. 12.13. Cinnamomum Scheuchzeri. 14.15. Cinnamomum lanceolatum. 16. 17. 18. Eugenia haeringiana. 19. Celastrus pseudoilex. 20. Leguminosites arcolatus. 21. Suprestites ? Falconeri.



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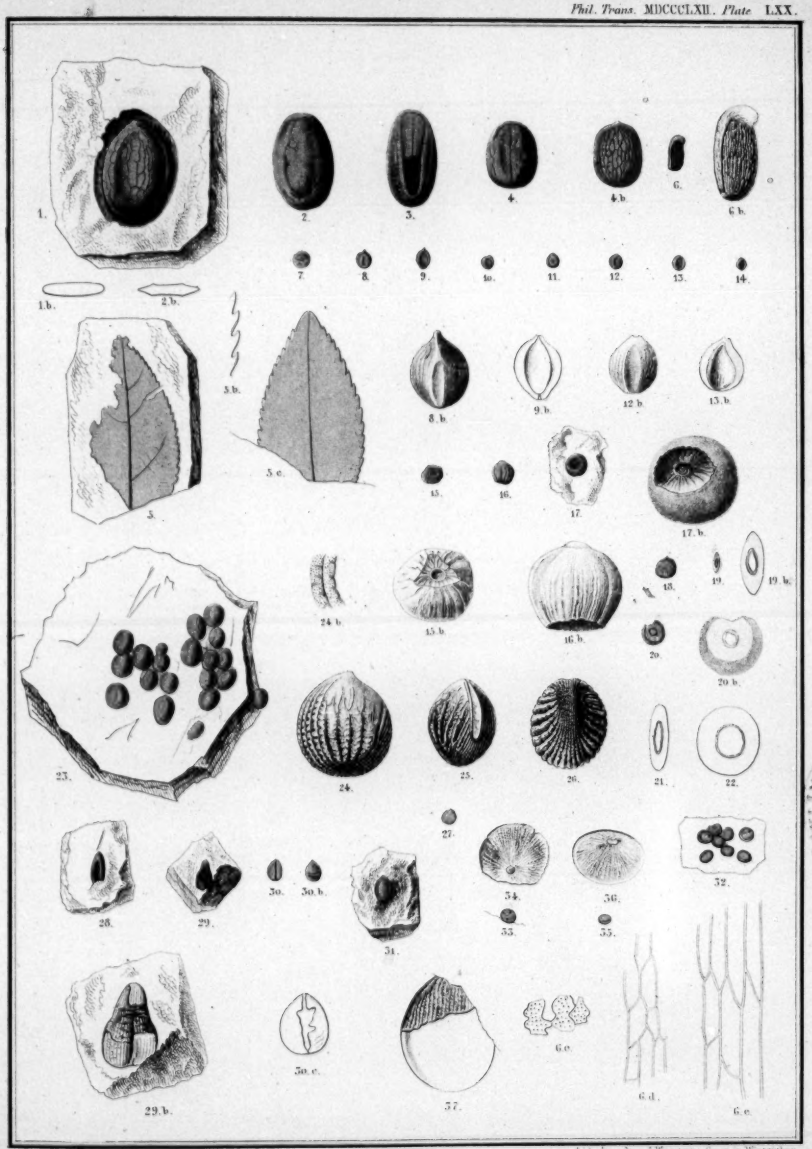
P. Bruyier del. Lith. Anstalt v. J. Wurster u. Comp. in Winterthur.

1–8. Gardenia Wetzleri. 9. 10. Eucalyptus oceanica ? . 11–17. Nyssa europaea. 18. Nyssa laevigata. 20–25. Nyssa striolata. 24. Nyssa microsperma. 25. 26. Vitis britannica. 27. 28. 29. Vitis Hookeri. 30. Carpolithes scutellatus.



P. Brugier del. Lith. Anstalt v. J. Wurster u. Comp. in Winterthur.

1–3. Anona devonica. 4. Anona cyclosperma. 5. Pterocarya denticulata ? 6. Carpolithes Websteri. 7–14. Carpolithes Bowerianus. 15–23. Carpolithes nitens. 24–27. Carpolithes exaratus. 28. 29. Carpolithes vinaceus. 30. 31. Carpolithes lividus. 32–37. Nymphaea Doris.

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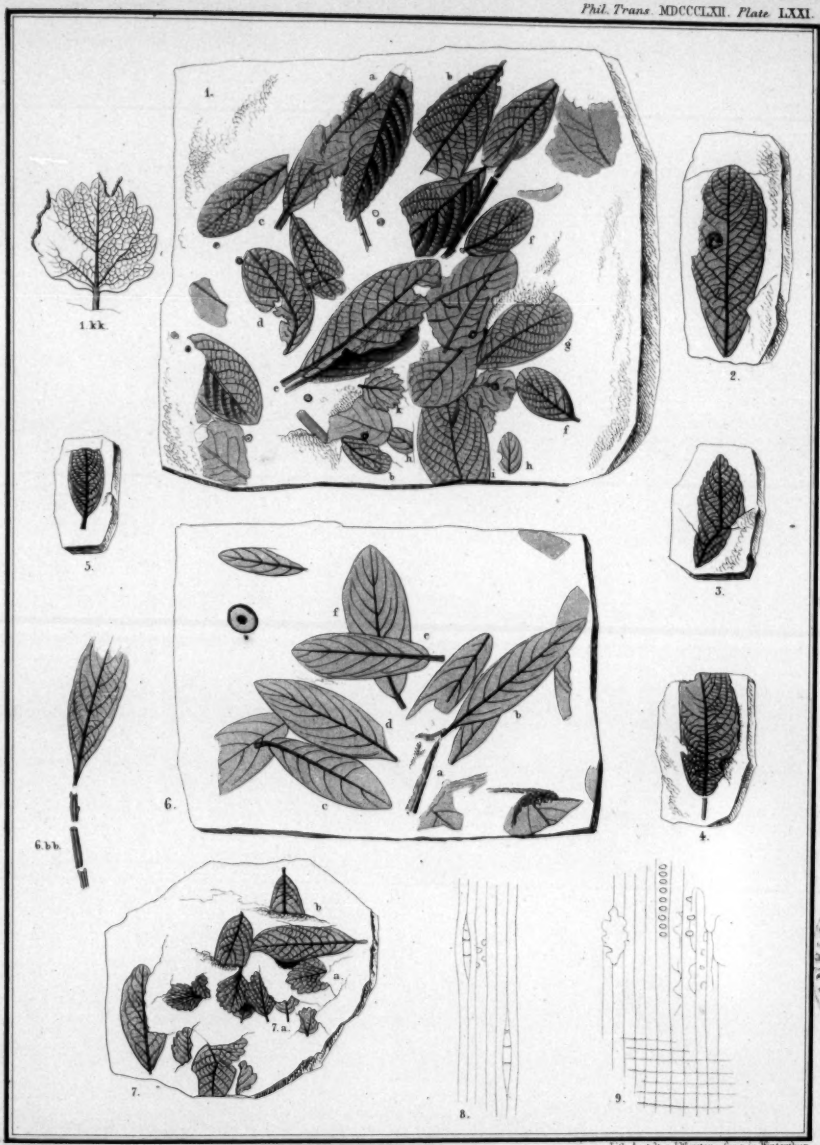

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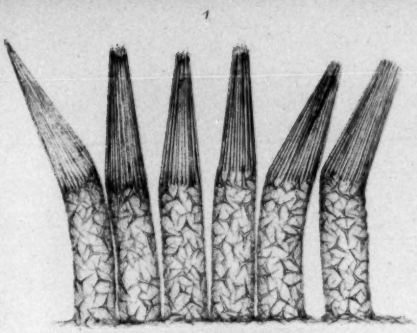
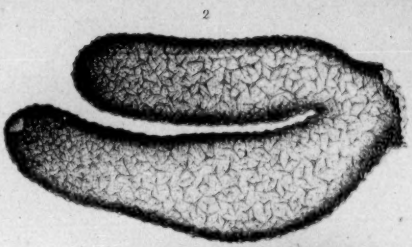
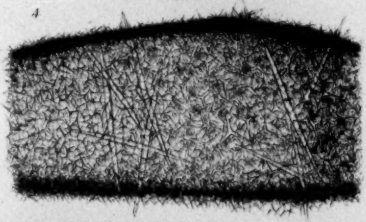
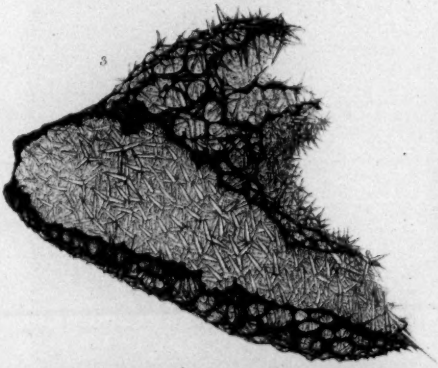
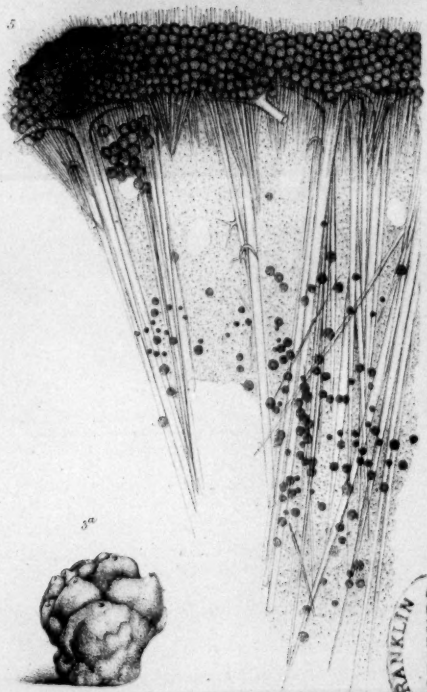
1. k. Betula nana. 1. a. b. Salix cinerea. 1 c..h. Salix repens L. ♀ 2. 3. Salix cinerea 4. 5. Salix sp. 6. 7. Salix repens L. ♀ 7. a. Betula nana.

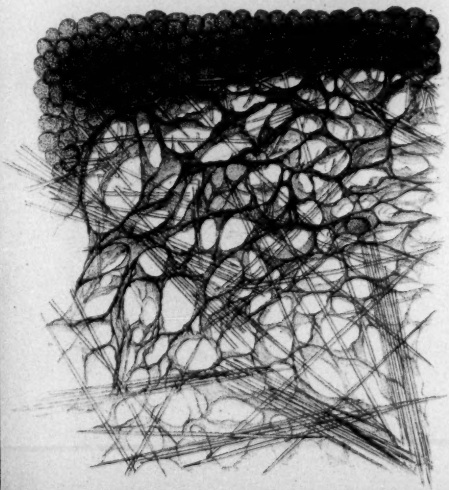












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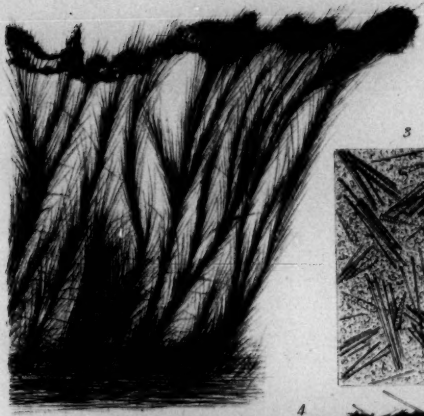
Drawn & Lithographed by W. Lane Adams.

J. Basire imp.

1



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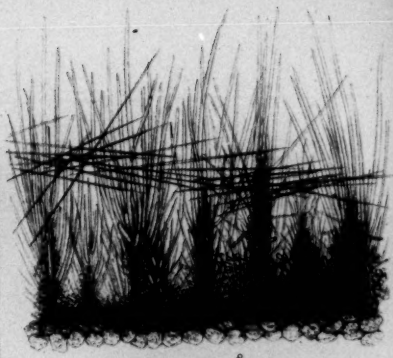

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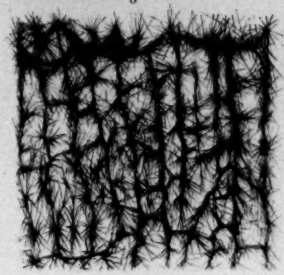

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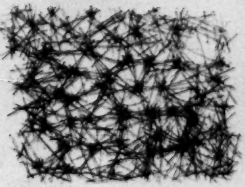

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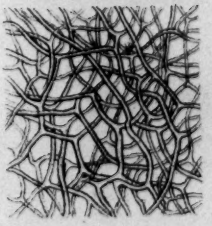

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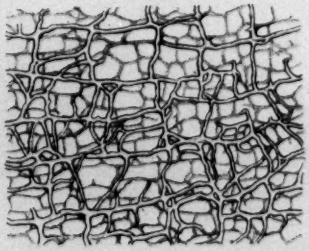

11

Drawn & Lithographed by W. Lens Addison.